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GEOLOGICAL MAGAZINE

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# Inclined Granitic Pipes in the Diorites of Guernsey

By R. W. D. ELWELL, R. R. SKELHORN, AND A. R. DRYSDALL

(PLATE IV)

ABSTRACT

Pipe-like bodies, of granitic composition, occur in certain meladiorities in Guernsey. Their average diameter is 3 inches, and they are all similarly inclined. Some connect downwards with an acid vein system; others with a discontinuous acid layer. It is considered that the pipes were formed before the meladiorite host rocks had solidified, and that their inclination was the result of relative movement between the rocks above and below.

## INTRODUCTION

THE following study of inclined pipes was begun at the suggestion of Dr. A. K. Wells, who has been interested for some time in the relations between acid and basic rocks in the Channel Islands. Dr. Wells had supervised the research work in Guernsey of one of us (A.R.D.), who was then concerned with the igneous complex as a whole. It was in the course of this research that the pipes were first observed; and the account of their origin tentatively proposed at that time was not greatly different from the conclusions which, with further work, we have jointly reached.

Guernsey is divisible into two geological regions. The southern and larger part consists of gneisses and schists, and the northern part of plutonic igneous rocks (probably of Hercynian age) with minor intrusives. This igneous complex includes several granites and a gabbro, but is largely composed of diorite. The pipes occur locally in the diorite.

It was decided to confine attention to a short stretch of coast to the north-east of La Rochelle, a village a mile or so north of St. Samson harbour. On the 6-inch maps of the Ordnance Survey this rocky piece of coast (about 150 yards long) includes the point marked " Beaucette Battery ". We use this name to denote the locality.

The diorites here include a band of meladiorite, about 6 feet thick (Plate IV, fig. 1), and thinner bands of the same rock at higher levels. The pipes occur in the meladiorites, especially the main one, in which several hundred are exposed, each 2–4 inches in diameter. They are inclined (on the average) at 30° to the horizontal, and all plunge in the same general direction, between south-east and south. The pipes in the main meladiorite have about twice the diameter of those in the

thin meladiorites. In these, pipes are not common, but those which are seen are of special interest; for, whereas it is possible to doubt whether the large pipes are related to veins, the small ones (in the thin meladiorites) patently connect downwards with a vein system. We believe that the large pipes are in fact *indirectly* related to veins, and that all the pipes were fed from vein material.

## The Rocks of Beaucette Battery

The Beaucette Battery diorites are of fairly uniform appearance, though (as stated above) they include bands of meladiorite. These dip at 20° to the west. Locally, there is a further, less pronounced banding, which has the same attitude. The diorites—but not the meladiorites—are freely veined with acid material, mostly in thin sheets which in the main are parallel to the banding, though in detail they may be highly irregular, with frequent protrusions and cross-connections. Immediately below the main meladiorite there is a light-coloured diorite, which varies in thickness from about 5 feet down to a few inches; and in the extreme south of the exposures it is absent. The relationships are shown in Text-fig. 1, the light-coloured diorite (leucodiorite) being marked with a vertical ruling.

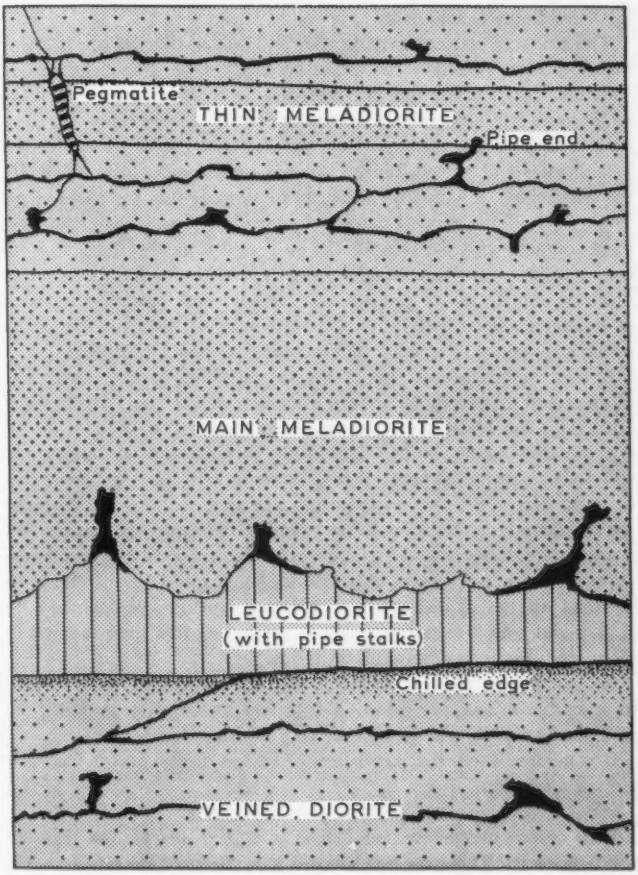
It may be seen from Text-fig. 1 that the contact between the leucodiorite and the main meladiorite is highly irregular. Apophyses of the former protrude upwards into the meladiorite. Many of these apophyses lead up to the lower ends of pipes. They are, in fact, stalk-like connections to the pipes, which are thus rooted in the underlying layer. In the upper parts of the stalks, near where they join pipes, the leucodiorite gives place to more acid rock (shown black in Text-fig. 1), and this more acid rock is co-extensive with the material of the pipes. Further details of these structures are given in a later paragraph.

The terminal relations of the small pipes are also indicated in Text-fig. 1, the " pipe end " being the point of connection with the veins of the veined diorite. It is evident that the pipes have formed at points where the vein system extends to the base of the meladiorite. Only two of the small pipes have their ends exposed.

The meladiorites are cut by steeply dipping pegmatite sheets which vary from about 1 inch to 1½ feet across. Many of them are rather variable in strike. A curious feature of these pegmatites is that they are almost, but not quite, confined to the meladiorites in which they occur. Each one protrudes a little above the top and a little below the base. Acid veinlets diverge from the ends and generally seem to connect with the vein system of the diorite, though at one point veinlets from a pegmatite are seen to cut the normal veining.

Evidence of chilling suggests that much of the Guernsey diorite complex was built up by successive sheet intrusions. At Beaucette

Battery the veined diorite of the lower part of the section (Text-fig. 1) has chilled against the base of the leucodiorite, and it was thus intruded




TEXT-FIG. 1.—Diagrammatic section of the rocks at Beaucette Battery. The section, which is vertical, is in a plane not containing the inclined pipes.

into that position. The main meladiorite was likewise intrusive in respect to the leucodiorite, as it has a chilled margin at its base. The highly irregular contact between the two is interpreted as due to

mobilization of the leucodiorite following the intrusion of the meladiorite magma. Thus, in the lower part of the section, both the veined diorite and the meladiorite post-date the leucodiorite, and show intrusive contacts against it.

The contacts between meladiorites and veined diorites are in many places diffuse, especially the upper contacts of the thin meladiorites. This may mean either that the meladiorites were intruded into rocks which were still hot, the mutual contamination effects being, for some reason, more marked at the top; or else that the contacts between meladiorites and veined diorites are not intrusive contacts at all. In the latter event, it would be necessary to suppose that the rocks of the lower part of the section came into position already differentiated, their contacts with the leucodiorite raft indicating that they were, in fact, intrusive. On this view, it is likely that the rocks above (being precisely similar veined diorites and meladiorites) were also intruded as a heterogeneous body. We are not concerned with the manner in which they could have been differentiated at their former site.

It was implied above that, if the relationships between the meladiorites and veined diorites were intrusive, it was the former which intruded. The evidence for this is mainly indirect; it depends on the interpretation we put on the relationship between veins and pipes, and will not be considered here. It may be remarked, though, that at two or three points the thin meladiorites are seen to taper off and end rather abruptly, and then take up again on the same line, several feet away; and this may be held to support the sequence we have proposed. On the other hand it could be maintained that more weight should be attached to the evidence of their upper contacts, which may be gradational over 8 inches or more, as suggesting that their relation to the veined diorite is not an intrusive one.

In summary, the probable intrusion sequence was either: (i) leucodiorite and (ii) veined diorite and meladiorite together; or (i) leucodiorite, (ii) veined diorite, and (iii) meladiorite.

It is assumed here that intrusions of veined diorite and meladiorite did not alternate.

### The Veining in the Diorite

Very commonly the veined diorite is chilled against the material which veins it. This may be observed with the unaided eye, and it is confirmed in thin sections, where the grain-size of the diorite is seen to decrease progressively towards the contact with a vein. The phenomenon whereby a vein system has caused chilling in the enclosing rock is described by Bailey and McCallien (1956, p. 491) for the Tertiary igneous complex of Slieve Gullion, N. Ireland. Here, the dolerites in the layered succession are often chilled against the granophyre veins which cut them. The authors cited maintain that the

material of the veins was produced by rheomorphism of the granophyre country rock into which the dolerites were intruded as sills. When first introduced, the vein granophyre was at a lower temperature than the host dolerite; and, since the dolerite had not then completed its crystallization, it was chilled against the veins. Certain granophyre veins in the Carlingford complex, described by Bailey (1959, p. 144) have produced similar effects.

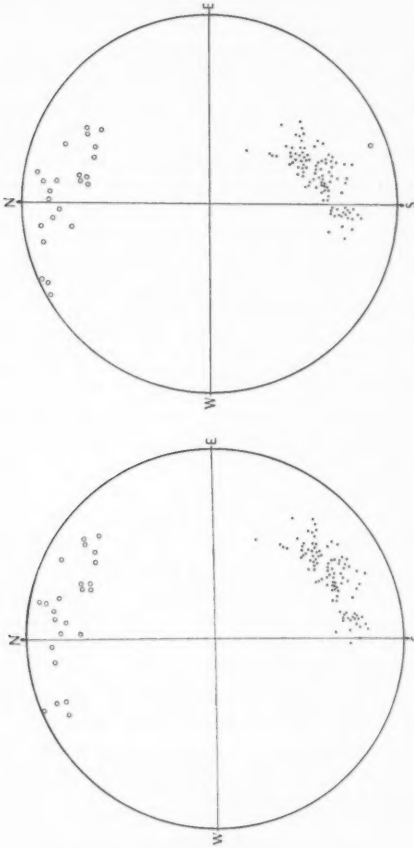
At Beaucette Battery the vein material is dominantly in layers (themselves irregular) which are parallel to the sheeting of the complex, and it is therefore unlikely that the veins ever occupied incipient fractures in diorites which had begun to solidify. It is more reasonable to regard them as having been introduced into the diorite while it was still fluid, and as having acquired their largely planar disposition as a result of laminar flow in the host. If so, it might be expected that the vein material, being lighter than the dioritic host, would have tended to move upwards, away from the layers in which it was brought in. The forms of some of the veins suggest that this has, in fact, occurred. In such veins the base tends to be flat, and wisps and tongues of material protrude upwards from the top. However, the few veins which show these features well are all adjacent to veins which show them equally well in reverse—in which the *tops* tend to be flat and the protrusions are directed *downwards*. Plate IV, fig. 2 shows one such opposed pair. Chilling of the diorite is much more marked against the flat contact of the vein, whether top or base, than against the irregular one. These phenomena seem difficult to explain; yet, on the "two-liquid" theory of vein formation, as proposed above, the possibility of overturning is not excluded. It would not be remarkable if thin sheets of acid magma, carried along in more basic magma, sometimes became partially folded back on themselves. It might be argued that the apophyses could not survive the overturning—even though the marginal chilling effects might tend to preserve them—so that the inversion hypothesis would not do. In that case, the existence of opposed projections on adjacent veins is indeed remarkable.

It should be emphasized that many of the veins have projections which may be due to kinking or to squeezing out of the vein material, upwards or downwards, so that relationships of the kind described above are for the most part obscured.

## The Pipes

Compared with other pipe structures which have been described in geological literature the Beaucette Battery pipes display an unusual regularity. In this respect they resemble the granophyre pipes of Slieve Gullion (Elwell, 1958) which, however, stand vertically in dolerite.

The plunge values of one hundred pipes are given in Text-fig. 2A, which is a lower-hemisphere projection on a Schmidt net. Poles to twenty-four pegmatite sheets are shown on the same diagram. It appears that there is no symmetrical attitude relationship between




TEXT-FIG. 2.—A. Stereogram showing plunge values of 100 pipes (dots) and poles to 24 pegmatites (circles). B. The same, rotated 20° about a horizontal axis trending 5° E. of N.

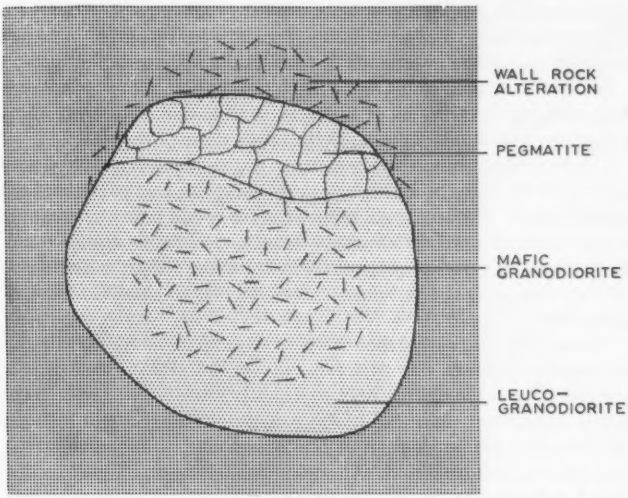
pipes and pegmatites; but, when the 20° dip of the meladiorite layers is imagined to be restored to the horizontal it is then seen (Text-fig. 2B) that the asymmetry is not marked. It is our opinion (see below) that the pipes and pegmatites are genetically related.

The horizontal axis about which the projection shown in Text-fig. 2A

was rotated to give that shown in Text-fig. 2B was 5° E. of N., this being the average strike of the banding.

Where exposures provide more or less longitudinal sections of pipes it is clear that many of them are nearly straight. One or two such sections are remarkably straight (see Plate IV, fig. 1).

In cross-section the pipes are usually more or less circular or elliptical, but a few of them are rather irregular, and even sub-angular, though simple in outline. Conditions of exposure are such that it is not easy to determine the shapes in true cross-section of more than a limited




TEXT-FIG. 3.—Cross-section of a pipe exposed on a vertical joint face. The actual diameter is 3½ inches.

number of pipes. It appears, however, that insofar as they are elliptical there are no preferred directions for the longer and shorter diameters. Neighbouring pipes are sometimes connected by thin acid stringers.

The material of the pipes is granodiorite. In each pipe cross-section a pegmatite patch is seen at the top, against the periphery (Text-fig. 3). Such pegmatite has formed along the topmost surfaces of the inclined pipes, but is no more prominent at the upper *end* of a pipe than lower down. The proportion of pegmatite varies for different pipes; it is generally quite small, but one or two pipes were observed to be dominantly pegmatitic.

Many pipes have a zoned structure, the core being more intensely

flecked with biotite than the rim. This effect is illustrated in Text-fig. 3, which also shows the form of the wall-rock alteration. This involves the growth of biotite and quartz, in a zone above the pipe.

It seems likely that the pipes extend from bottom to top of the meladiorite host rocks. At any rate, several pipe cross-sections are seen in the main meladiorite within a few inches of the upper contact, where they have retained their more or less circular forms. Pipe material is not anywhere seen to protrude up into the overlying veined diorite.

The direct connection to veins shown by the pipes in the thin meladiorites is seen at two points. Where each pipe joins with the vein system there is a concentration of acicular hornblendes—a feature observed also at the lower ends of pipes in the main meladiorite.

It has already been stated that these pipes connect at their lower ends with stalk-like protrusions of the underlying leucodiorite, there being a development of acid material in the upper parts of the stalks.

Three-dimensionally, these structures are ridge-like, and they have a trend which perhaps agrees (more or less) with the azimuth of the inclined pipes. Exposures are not such as to reveal how persistent the ridges may be; nor how closely they conform to a particular trend. Such as it is, the evidence suggests the interpretation given in Text-fig. 4, but the ridges may not be so closely parallel, nor so simple in form, as shown here.

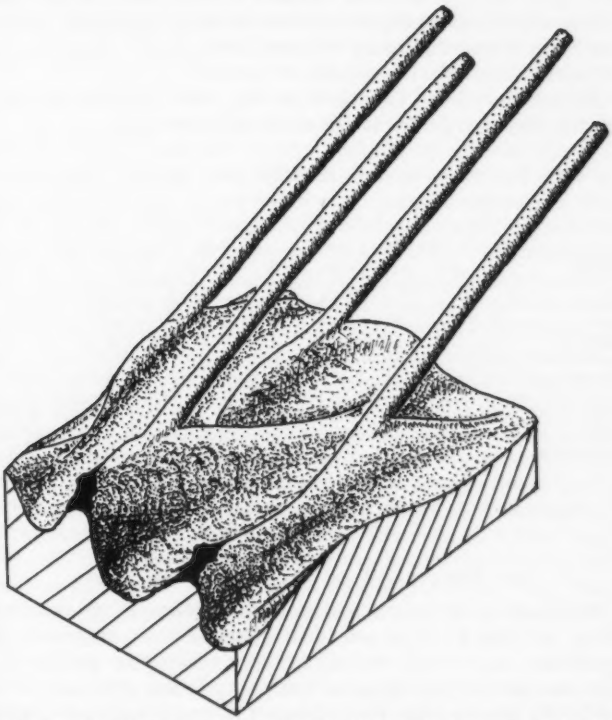
Polished sections reveal that there is no sharp dividing line between leucodiorite and overlying acid material. In one such section there is a mixed zone in which the relationship between the acid and leucodiorite components indicates flow. It appears that the acid material had risen into the upper parts of the leucodiorite while the latter was in a liquid or soft condition. At one or two points on the cliff section there is a direct cross-connection between acid material along the base of the leucodiorite (Text-fig. 1) and that which occurs discontinuously along the top. Such cross-connections widen smoothly into lower and upper acid layers. Towards the south end of the section the leucodiorite becomes very thin, and in the extreme south (as stated) it is absent. The pipes then connect directly with a thin acid layer above the veined diorite.

In thin sections it is seen that the pipes are composed of plagioclase, biotite, and quartz, with some perthite, mainly in the pegmatitic part. The inner and outer zones (Text-fig. 3) differ only in proportion of biotite.

The plagioclase, which is an oligoclase-andesine, exhibits combinations of Carlsbad, albite, and pericline twinning. In contact with quartz the sections tend to be straight-edged, but otherwise they are rounded. Quartz occurs as aggregates, about 2 mm. across, consisting

of numerous highly irregular individuals. These aggregates have straight margins against feldspar and biotite. Some of the biotite has been replaced by chlorite and prehnite. The mode of the granodiorite of the central zone is given in Table 1.

In the pegmatitic parts of the pipes the feldspar, which consists of



TEXT-FIG. 4.—Diagram to illustrate the relationship between the inclined pipes and the ridge-like structures to which they connect.

oligoclase-andesine and perthite, is present as large crystals about 1 cm. across, the perthite being much the less abundant. Quartz forms aggregates of irregular grains, the average grain-size being about 0·5 mm. Biotite (partially altered to prehnite) is present in small amounts.

## THE PEGMATITE DYKES

Many of the pegmatite dykes are zoned. The largest one, which is

at the extreme north end of the exposure, has a five-fold structure of A-B-C-B-A type.

The outer zone (½–3 inches wide) is of granodiorite (A); the next zone (1–3 inches wide) is of coarse graphic pegmatite (B); and centrally there is a zone mainly composed of quartz (C). The feldspar of the graphic pegmatite is pink perthite and cream-coloured oligoclase-andesine, the crystals being set normal to the walls of the dyke. Biotite may occur in the outer zone as distorted flakes, extensively replaced by prehnite. Clinozoisite has also been observed.

We have stated that the pegmatites only occur in the meladiorite, but that they extend a few inches above and below them.

TABLE 1.—MODAL ANALYSES OF ROCKS FROM BEAUCETTE BATTERY

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Quartz . . . . | 1·0 | 2·5 | 1·6 | 22·4 | 13·1 |
| Plagioclase . . . | 68·2 | 48·4 | 18·7 | 65·2 | 64·3 |
| Perthite . . . . | — | — | — | 2·3 | — |
| Hornblende . . . | 25·0 | 46·1 | 77·2 | 0·4 | 17·0 |
| Biotite . . . . | 1·6 | 0·6 | 2·5 | 8·4 | 3·7 |
| Accessories . . . | 4·2 | 2·4 | — | 1·3 | 2·0 |

1. Leucodiorite. 2. Veined diorite. 3. Meladiorite. 4. Pipe material. 5. Granitic vein material.

## THE PETROGRAPHY OF THE DIORITES AND VEINS

Representative modal compositions of the different rock types are shown in Table 1. It is seen that the variation in proportion of hornblende accords with the nomenclature adopted for the diorites. It is also apparent that the pipe material is notably more acid than that of the granitic veins, the proportion of quartz and biotite being much higher, and hornblende virtually absent.

*The leucodiorite.*—The rock is composed of plagioclase and hornblende (to a small extent replaced by biotite) with accessory magnetite and a little quartz. The plagioclase occurs as abundant subrectangular or ovoid crystals, about 2 mm. across, and as small crystals in the groundmass, along with hornblende. The core of each plagioclase individual is intensely turbid, the rim being clear andesine which may show faint oscillatory zoning. The hornblende has little tendency to be euhedral.

*The veined diorites.*—In these rocks plagioclase and hornblende are

present in equal amounts. The plagioclase crystals are rectangular, and are about 0·5 mm. across. As in the leucodiorite, they have turbid cores and transparent rims of andesine. Quartz is present in small amount, as aggregates (0·3 mm. across) and also as small single grains. Magnetite, zircon, sphene, and apatite are seen as accessories; and, as alteration products, chlorite and epidote.

The fine-grained margins against granitic sheets are generally ¼–½ inch wide. The texture is granular and there is more biotite than in the unchilled rock, but hardly any quartz.

*The meladiorites.*—The colour index and coarseness of grain distinguish these rocks from the other diorites. The plagioclase sections are rectangular, though their outlines are irregular in detail. They are about 3·5 × 2·5 mm. in size. The amphibole is seen as large squarish sections, up to 3 mm. across, and as small, irregular individuals. It is of two kinds: blue-green hornblende and colourless tremolite (included under " Hornblende " in Table 1). The amphibole is often moulded on to the plagioclase. There are small quantities of biotite and quartz.

The chilled margin at the base of the main meladiorite is about 1 cm. wide. It consists of granular amphibole and plagioclase, of grain-size 0·2–0·3 mm., and includes some plagioclase phenocrysts.

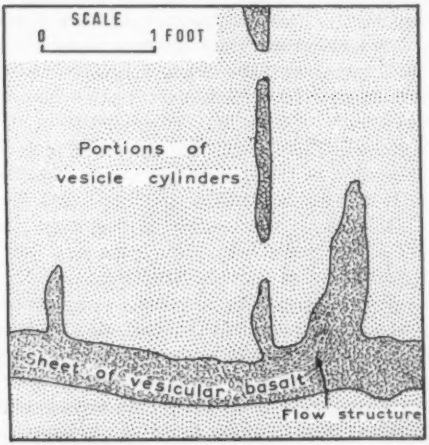
The zone of altered meladiorite above each pipe (see Text-fig. 3) makes fairly sharp contact with the pipe pegmatite below and the unaltered meladiorite above. The altered zone consists of quartz and biotite, in about equal amounts, with subordinate plagioclase. A more limited quartz enrichment extends further into the meladiorite.

*The granitic veins.*—The vein material, which is granodiorite, is rather variable in composition. In Table 1 the average of three modes is quoted. Euhedral plagioclase (andesine) is accompanied by a little irregular orthoclase. The feldspar is patchily sericitized. Hornblende occurs as acicular crystals; and biotite may be present, though much of it has been pseudomorphed by an emerald-green chlorite, which may contain lenses of epidote or prehnite. There are interstitial aggregates of quartz. As accessories, magnetite is widespread and sphene sporadic.

## The Origin of the Pipes

It seems probable that the pipes were formed by the rise of acid magma into the heavier magma of the meladiorite sheets, and that their inclination is the result of movement in the enclosing medium. A similar mechanism (without the movement) has been invoked for the granophyre pipes of Slieve Gullion (Elwell, 1958). The main evidence for this view derives from the demonstrable principle that regular pipe-like bodies of one material in another may form—under suitable conditions—where a denser fluid overlies one which is less dense, provided that the two are not readily miscible. This is, in fact, the

principle implicit in the widely accepted explanation of pipe amygdales. Shrock (1948, p. 352) gives an interesting summary of views on pipe amygdales, and he refers also to certain " vesicle cylinders ", which have been described by Du Toit (1907). These are nearly vertical cylinders of amygdaloidal rock, occurring in almost horizontal lavas of the Ventersdorp System of South Africa. They are of interest in that their scale and degree of regularity are of the same order as for the Guernsey pipes. Du Toit (1907, p. 15) states that they vary in diameter from 1–6 inches; and that in cross-section they may be " circular, elliptical, crescentiform, or a little irregular in outline ".




TEXT-FIG. 5.—Relationships seen in a fallen block of basalt. Locality:—Snjófell, Seydisfjördur, E. Iceland. Traced from a photograph lent by Dr. G. P. L. Walker.

Similar structures have been observed by Dr. G. P. L. Walker (personal communication) in some of the basaltic lavas of Iceland. These rocks contain numerous pipes of vesicular lava which connect with more or less horizontal sheets of the same material. Such connections, seen in a fallen block of basalt, are illustrated in Text-fig. 5, which is traced from a photograph kindly lent by Dr. Walker. In places the vesicles are drawn out by flow. It seems clear that the pipes were formed by upward movement due to the density difference between vesicular and non-vesicular lava. Dr. Walker makes some reference to these structures in his paper on the Reydarfjordur area, Eastern Iceland (1959, p. 373).

In the laboratory it is not difficult to produce pipes of one material

in another, but some of the pipe material comes to the surface of the host, and forms a layer at the top. Thus, when glycerine at a temperature of 125° C. is poured on a layer of solid Lakeside 70 [1] in a baking tin, some of the Lakeside 70 comes to the surface of the glycerine by way of numerous pipe-like feeders. When, on cooling, the glycerine is poured away it is seen that all the pipes, now solid, are of about the same diameter (1 mm. to 3 or 4 mm.) and that many of them no longer connect with the upper layer (Plate IV, fig. 3). It may also be observed that the pipes join downwards with ridges, and thus tend to have a linear disposition. The pattern of ridges is partly determined by the shape of the vessel, as some of them form parallel to its sides, others being more or less irregular. If the surface of the Lakeside 70 is partly vesicular, ridges will form initially in these parts.

The pipes produced in experiments of this kind show a marked downward widening into the ridges from which they are given off. This is a feature not observed in the Guernsey pipes. From Text-fig. 5 it appears that some of Walker's vesicle cylinders widen into the layers with which they connect and some do not. In the laboratory it is possible, using certain pairs of substances (e.g. dammar gum and paraffin wax), to produce pipes which show little or no downward widening. Such pipes may follow behind rising air bubbles, but they can form quite readily without assistance of this kind.

If it may be granted that the question of downward widening is not necessarily critical there still remains the problem of the upper layer: we were unable to form pipes without also producing an upper layer of pipe material. It should be mentioned that at Slieve Gullion there may be no difficulty in this respect because the pipes appear to become more and more hybridized upwards, and so progressively more stagnant. In Guernsey, however (in the main meladiorite, it is clear that many, perhaps all, of the pipes reach the top of the meladiorite layer; and one is forced to conclude either that the pipe material was held against the roof without spreading to form a layer, or else that such a layer was formed, and was in some way dispersed.

The literature of economic geology contains several accounts of pipe-like bodies associated with igneous rocks. They include the E. Australian ore bodies described by Blanchard (1947); the Potgietersrus tin pipes of S. Africa (Strauss, 1954); and the pegmatite pipes of the Quincy granite, Massachusetts (Warren and Palache, 1911). Blanchard's pipes occur in granite, and also in the surrounding country rocks. Their location is controlled by joints and fissures. They are irregular in attitude, and show great variation in size, the diameters ranging from 2 feet to more than 60 feet. The Quincy granite pipes are likewise irregular; of the three pipes described by Warren and

[1] A cement used in the preparation of thin sections of rocks.

Palache one is vertical, another horizontal, and the third inclined at 45°. Strauss (p. 62) says of the S. African tin pipes (which vary in diameter from 3–60 feet) that they pinch and swell, branch and unite, and twist and turn in all directions.

The ore and pegmatite pipes cited in the last paragraph were probably formed metasomatically (see the accounts quoted), the metasomatism having been controlled by joints and fissures (Blanchard) or by the distribution or movement of volatiles in the host rock immediately before its consolidation. Douglas (1957) has adduced experimental evidence in support of the idea that a stream of volatiles passing through a solidifying magma may leave an irregular pipe-like channel, which, with the passage of hydrothermal solutions, could become mineralized by infilling, or could serve as an axis of metasomatism. As an example of a pipe which may have formed in this way Douglas cites (and figures) one of the ore bodies at Lynn Lake, Manitoba, described by Hunter (1951).

We maintain that the Guernsey pipes are more to be compared with pipe amygdales and vesicle cylinders than with the ore pipes familiar to economic geologists. By contrast with these they are small-scale phenomena, which display a regularity in size, shape and attitude that is not approached by the ore pipes. We repeat that in our view it is this regularity, experimentally reproducible, which provides the strongest indication that the pipes were formed by the rise of one magma into another. In particular, we draw attention to the limited diameter range. On theoretical and experimental grounds it would seem that a very great range in diameter for magmatically formed pipes (in a single environment) would be a hydromechanical impossibility. Conversely, the evidence from the ore-pipes suggests that metasomatism could not produce equal-sized parallel cylinders, all of similar inclination. It may well be that magmatically formed pipes could be less regular than those at Beaucette Battery, such that their origin might be in doubt; but when the regularity is *there*, in a large group of pipes, the evidence (if the argument is sound) is unequivocal.

The following classification, for pipes of igneous or hydrothermal affinities (excluding volcanic pipes and breccia pipes), seems to be suggested:—

1. *Pipes of metasomatic origin*—irregular in size and inclination.
   (*a*) Metasomatism controlled by joints and fissures.
   (Not confined to igneous rocks.)
   (*b*) Metasomatism controlled by pre-existent volatile paths.
   (Confined to igneous rocks.)

2. *Pipes of magmatic origin*—regular in size and inclination.
   (Confined to igneous rocks.)

It is not intended to imply that there is necessarily a sharp distinction between pipes of category 1 (*a*) and certain breccia pipes. Nor does the classification given take account of pipe amygdales, though it could do so with a change in terminology.

Small-scale zoned pipes, evidently of metasomatic origin, have been described by Taylor (1940). These pipes, which are mainly vertical, occur in marls which have been hornfelsed by the Brockhill dyke (Worcestershire) and they consist of calcite, analcite, garnet, and other minerals. From examination of hand-specimens, kindly lent to us, we would describe them as irregular, though, as stated by Taylor (p. 540) they " bear a superficial resemblance to pipe amygdales ". It is not clear what was the metasomatic control, and it is therefore difficult to place them in the classification proposed above.

We have not yet discussed the inclination of the Guernsey pipes. Du Toit (1907, p. 14) figures a specimen of basalt containing pipe amygdales which are inclined and more or less straight (his figure being reproduced by Shrock, 1948, p. 354). The inclination is, of course, attributed to flow in the basalt. It would seem, however, that pipes several feet long ought not to remain straight under similar conditions because laminar flow would be differential, and should produce curved forms. Thus, it is necessary to suppose that the Beaucette Battery pipes did not begin to form during the intrusion of the meladiorites, but somewhat later, and that they acquired their inclination by a relative movement which affected the whole dioritic pile, the upper layers moving northward relative to the lower layers. It is considered that when the meladiorites became solid enough to crack the pegmatite fissures were produced in response to continued movement. The approximate symmetry of Text-fig. 2B supports this conclusion.

We would maintain the following sequence of events at Beaucette Battery:—

(1) The formation of the leucodiorite.

(2) The intrusion of the veined diorites, perhaps as successive sheets, the vein material being brought in as layers in the host magma.

(3) The intrusion of the meladiorites, with softening of the leucodiorite below the main meladiorite.

(4) The rise of vein material as pipes, into the sheets of meladiorite magma, whenever these cut the vein system, or (for the main meladiorite) where vein material accumulated at the base.

(5) A relative movement between the rocks above and below the meladiorites (not yet consolidated) causing the vertical pipes to become inclined.

(6) The formation of fissures in the more nearly consolidated meladiorites, in response to continued movement, the fissures being

filled with acid magma derived from the vein system, to form the pegmatite sheets.

(7) The westward tilting of the layers through 20°; this occurring before the solidification of the pipes.

As previously indicated, stages (2) and (3) may have been simultaneous. Also, it is possible that the movement which caused the pipes to become inclined may have accompanied their formation, in which case they were never vertical.

There are certain phenomena which we have not attempted to explain. One of these concerns the development of pegmatite in the pegmatite dykes and along the upper margins of the pipes. For some reason the acid rocks were able to assume a pegmatitic facies only within the meladiorites, or just outside them—the pegmatite dykes extending a little above and below. It is possible that the acid magma was able to acquire volatiles from the surrounding meladiorite. Another problem is that the pipes in the main meladiorite are larger (in diameter) than those in the thin meladiorites. We cannot account for this, but we consider it more likely to be explicable in terms of fluid mechanics than metasomatic replacement. A third point is that the material of the pipes is more acid than that of the veins to which they connect. This may be due to gravity differentiation, as the pipes were held for some time as columns of acid magma. The concentrations of hornblende needles seen at the lower ends of several pipes supports such an interpretation. So also does the development of pegmatite along the upper margins of the pipes. The pipes must have been inclined when the pegmatite formed.

In summary, our main argument that the pipes represent an interliquid phenomenon is based on their regularity, as compared with pipes of which the metasomatic origin is not in dispute. The argument is supported by various subsidiary lines of evidence, which indicate that the pipe material was formerly in a magmatic state.

## Acknowledgments

The authors are indebted to Dr. A. K. Wells who introduced them to the igneous geology of Guernsey. They also wish to thank Professor J. H. Taylor and members of the staff at King's College for helpful discussion.

## REFERENCES

Bailey, E. B., 1959. Mobilization of Granophyre in Eire and Sinking of Olivine in Greenland. *Liver. and Manch. Geol. Journ.*, ii, 143–154.

—— and W. J. McCallien, 1956. Composite minor intrusions and the Slieve Gullion Complex, Ireland. *Liver. and Manch. Geol. Journ.*, i, 466–501.

Blanchard, R., 1947. Some pipe deposits of eastern Australia. *Econ. Geol.*, xlii, 265–304.

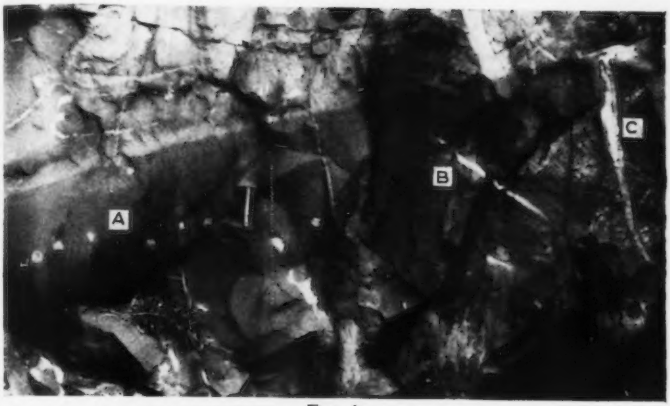



FIG. 1

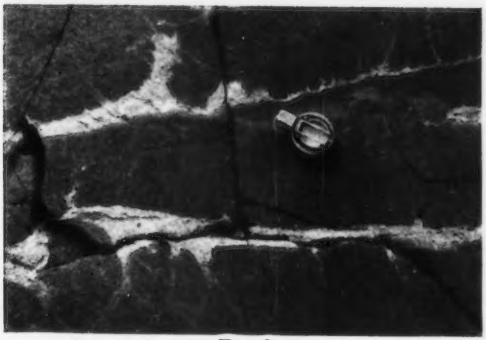


FIG. 2

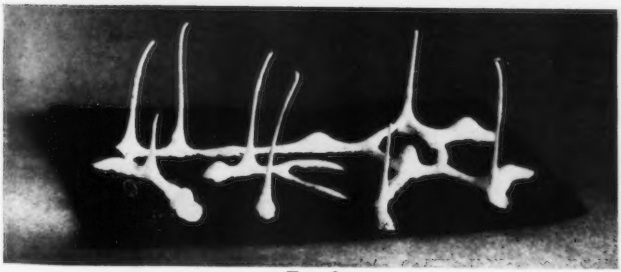


FIG. 3

*Facing p.* 104.

DOUGLAS, G. V., 1957. Pipe-like ore bodies in plutonic rocks. *Econ. Geol.*, lii, 578–581.

DU TOIT, A. L., 1907. Pipe amygdaloids. *Geol. Mag.*, xliv, 13–17.

ELWELL, R. W. D., 1958. Granophyre and hybrid pipes in a dolerite layer of Slieve Gullion. *Journ. Geol.*, lxvi, 57–71.

HUNTER, H. E., 1951. *M.Sc. Thesis.* University of Manitoba.

SHROCK, R. R., 1948. *Sequence in layered rocks.* McGraw Hill, New York.

STRAUSS, C. A., 1954. The geology and mineral deposits of the Potgietersrus tin-fields. *Union S. Africa Geol. Surv. Mem.*, xlvi.

TAYLOR, J. H., 1940. The composite dyke at Brockhill, Worcestershire. *Miner. Mag.*, xxv, 538–549.

WALKER, G. P. L., 1959. Geology of the Reydarfjordur area, Eastern Iceland. *Quart. Journ. Geol. Soc.*, cxiv (for 1958), 367–393.

WARREN, C. H., and C. PALACHE, 1911. The pegmatites of the riebeckite-aegirite granite of Quincy, Mass., U.S.A.; their structure, minerals, and origin. *Proc. Amer. Acad. Arts Sci.*, xlvii, 125–170.

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## EXPLANATION OF PLATE IV

FIG. 1.—Section showing the main meladiorite and overlying veined diorites. At A cross-sections of pipes are seen; at B a longitudinal section; and at C a pegmatite sheet. Old quarry at the south end of the exposures.

FIG. 2.—Acid veining in the veined diorite. The upper vein has upward projections, and the lower one downward projections. North end of the exposures.

FIG. 3.—Pipes formed by pouring glycerine at 120° C. on to a layer of solid Lakeside 70 in a baking tin. An upper layer of Lakeside 70 has been broken away from the pipes. The specimen has been painted so that the pipes, and the ridges to which they connect, are more clearly visible. About two-thirds actual size.

# Sedimentary Structures in the Epidotic Grits of Skye

By JOHN SUTTON and JANET WATSON

ABSTRACT

Sedimentary structures in the lowest sub-division of the Torridonian of Skye are described and figured. Trough cross-stratification of the type known as festoon bedding is widely developed in the coarser grits. Finer-grained sandstones show curly-bedding structures due to post-depositional disturbances. Siltstones and mudstones are characterized by a fine lamination and by such structures as ripple-marks, minute graded bedding and desiccation cracks. The orientation of cross-laminae in the festoon-bedded grits indicates that the currents depositing these rocks flowed towards the north-east or east.

## I. INTRODUCTION

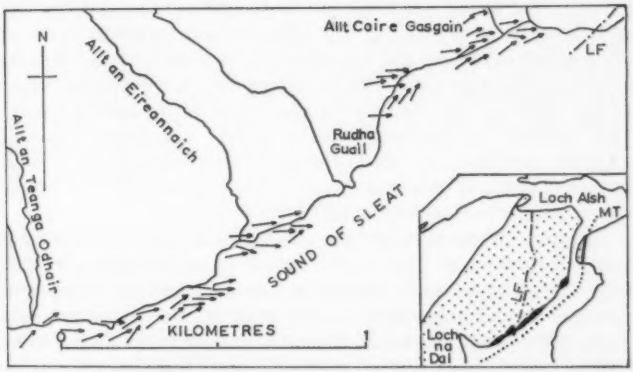
THE arkosic sandstones, shales, and conglomerates of the Torridonian formation make up, in the words of Teall, " one of the largest as well as one of the most ancient masses of mechanical sediment in the British Isles." The main source of published information on these sediments is still the Geological Survey Memoir on the North-west Highlands (Peach *et al.*, 1907), in which the general conditions of deposition are suggested to be " those of a rapid accumulation in shallow water near a shore-line subject to violent currents and the influx of flood or stream-borne materials . . . " (p. 273). Much of the Torridonian displays very characteristic sedimentary structures which vary significantly through the succession, and the present paper records the results of a local study of these structures in the Epidotic Grits, the lowest sub-division of the Lower Torridonian or Diabaig Group of Skye.

The Diabaig Group is seen in Skye at its maximum development and reaches a total thickness of some 2,000 metres. C.T. Clough, who was responsible for mapping the group, distinguished four sub-divisions and his account of these is given in the North-west Highland Memoir (Peach *et al.*, 1907, pp. 348–59 ; see also the summary in Peach and others, 1910, pp. 57–60). It can be supplemented by the more recent observations of Bailey (1955). The Epidotic Grits form the lowest hundred metres of the Diabaig Group and are presumed to rest directly on the eroded surface of Lewisian. They are followed by the Loch na Dal Beds, 60–120 metres thick, which consist of dark shales and grits with impure calcareous bands.

The main outcrop of the Epidotic Grits forms a narrow discontinuous belt along the coast of the Sound of Sleat north-east of Loch na Dal (Text-fig. 1). Some isolated outcrops appear also in the Sleat of Skye more than fifteen kilometres further south-west. These outcrops lie in a region of great tectonic complexity; as noted by Clough and by

Bailey (1955), they are very much deformed and they are therefore not considered here.

The belt of complication associated with the Moine Thrust at the margin of the Caledonides passes through south-east Skye and affects the whole of the Diabaig Group. The rocks form part of the Kishorn Nappe which is thrust westward over the foreland and is itself overridden by the Tarskavaig and Moine Nappes (see the Geological Survey 1-inch Map, Sheet 71, and Bailey, 1950). The principal structure within the Kishorn Nappe is the large Lochalsh syncline, which opens towards the west and has an inverted eastern limb. Its axial plane emerges on the Sound of Sleat about three kilometres north-east of Loch na Dal, and divides the outcrop of the Epidotic




TEXT-FIG. 1.—Locality map showing places mentioned in the text. Directions of palaeocurrents are shown by arrows. Inset: index map showing the outcrops of the Diabaig Group (stippled) and Epidotic Grits (black). LF: hinge-line of Lochalsh Fold. MT: Moine Thrust.

Grits into two portions—a south-western part belonging to the normal limb of the fold and a north-eastern part in which the rocks are inverted and considerably distorted.

South-west of the main fold hinge, the normal limb of the syncline is crossed by several small subsidiary folds associated with minor thrusts. The short reversed limbs of these folds are shattered, but the rocks of the long normal limbs, which are often almost horizontal, appear, both in the field and under the microscope, to be very little deformed; it is with these rocks that the bulk of our observations are concerned. Clough recorded a north-easterly increase in the degree of alteration of the Grits and showed that in this direction the clastic fragments became increasingly drawn out and the rocks were traversed by lustrous foliation planes. The lineation and cleavage so produced

(which are, we believe, younger than the Lochalsh fold) first become conspicuous at the north-east end of the bay east of Rudha Guail (Text-fig. 1).

## II. General Features

Clough's account of the Epidotic Grits (Peach *et al.*, 1907, pp. 351–4) is prefaced by the remark that " In no unthrust area of the Torridon Sandstone do we know of rocks quite like what those under description may be supposed to have been in their original condition ". They show, of course, many general resemblances to the rest of the formation, particularly in the variability of their grain-size, the angularity of the particles and the variety of minerals and rocks represented among the clastic fragments.

One of the special features noted by Clough was the predominance of yellow and green colours. The green tint was shown to be due to the presence of chlorite and the yellow to the abundance of fragments of epidote and epidotized feldspar derived from the weathered surface of the Lewisian. Among other detrital components noted by Clough were pebbles of quartzo-feldspathic gneiss resembling Lewisian, quartzite, and felsite, as well as grains of quartz, feldspar, hornblende, opaque minerals, sphene, and zircon. We have seen in addition biotite, muscovite, garnet, and serpentine.

The poor sorting of the sediments makes it difficult to give average figures for grain-size. The rocks range from conglomerates through grits and sandstones to mudstones, and were thought by Clough to be generally coarser than those of any other Torridonian division in Skye. Although on the Sound of Sleat it is, as he put it, " rare to find pebbles exceeding the size of a pigeon's egg," fragments of a centimetre or so in diameter are scattered through many rocks. The body of the rocks is made of angular particles of many sizes packed indiscriminately together, the size of the largest common particles determining the appearance in hand specimen. The interstices are often filled by a recrystallized growth of chlorite, white mica, and epidotic minerals. The field appearance of the rocks is controlled partly by their texture and partly by the character of the bedding and other sedimentary structures. These factors combine to produce a number of easily recognizable field types which may be listed as follows :—

(1) *Grits.*—The authors of the 1907 Memoir applied the term grit to many of the coarser Torridonian rocks. It can be retained for the coarse, badly-sorted rocks whose larger particles are readily visible to the naked eye—larger than, say, 2 mm. in diameter. *Coarse grits* contain many particles 0·5 cm. or more in diameter and are often pink as a result of the abundance of feldspar fragments. The grits are characterized by lenticular false bedding.

(2) *Arkosic sandstones* are rather finer and less variable in grain-size. Their larger grains are generally not more than 1 mm. across, but they may contain coarser layers or patches, or scattered coarse particles. They weather smoothly and give an impression of uniformity in hand specimen. In the field, they are often characterized by a form of curly-bedding structure.

(3) *Siltstones* are fine-grained rocks in which the bulk of the clastic particles cannot be distinguished with the naked eye. They are marked by a fine, fairly regular banding and are generally light grey, green, or yellowish in colour.

(4) *Mudstones* are very finely laminated purple or green rocks which are made up of very minute chips of detrital minerals set in a deeply-stained, indeterminate matrix.

(5) *Shales.* Thoroughly argillaceous rocks are scarcely represented in the Epidotic Grits, but dark grey shales appear in the Loch na Dal Beds immediately above. Rocks of this type are faulted down to the coast south of Rudha Guail and rest on the Epidotic Grits west of Allt an Teanga Odhair.

## III. Sedimentary Structures

The various types of rock making up the Epidotic Grits combine to form a number of associations, most of which recur several times in the succession. Each association possesses characteristic sedimentary structures which are described in the following pages.

The majority of the grits show false bedding of the type which Knight (1929) called festoon bedding (see McKee and Weir, 1953, for a general discussion of nomenclature). *Festoon-bedded grits*, making sequences of some metres with hardly any admixture of other kinds of sediment, form the first association to be considered. *Lenses of grit emplaced in finer-grained sediments* provide a second association. A third group consists of *arkosic sandstones* with occasional mudstone partings. A fourth is composed of rapid alternations of *sandstones, siltstones, and mudstones* and a fifth of *mudstones* alone. Finally, a *laminated series* of siltstones, mudstones, and shales is developed at the top of the Epidotic Grits where it forms a transitional group ushering in the Loch na Dal Beds.

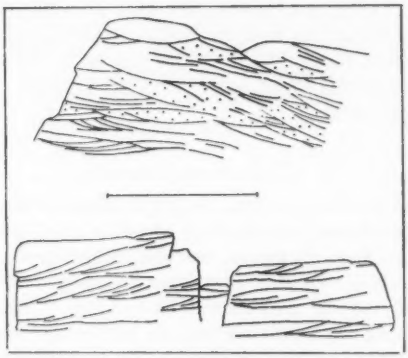
The separate associations mentioned above may form continuous sequences as thick as 10 or 20 metres but are commonly much thinner than this. The succession as a whole, built up of alternations of different associations, was estimated by Clough to be 2–300 feet thick. This figure seems if anything rather low, but the presence of a number of small faults and thrusts makes accurate correlations difficult. So far as can be seen, there does not appear to be a consistent rhythm

or a regular variation in lithology until the highest part of the group is reached.

*Festoon-bedded Grits*

Festoon-bedded grits are the commonest rocks of the group and are particularly well-exposed in the low cliffs and wave-cut platform on either side of the mouth of Allt an Eireannaich. Their most noticeable feature is the absence of continuous, parallel bedding-planes. The rocks are made up of large numbers of lenticular units stacked together in characteristic ways. The units are generally elongated and so produce different patterns in profile and in longitudinal section (Text-fig. 2).

The structure of the grits reflects their mode of deposition. They



TEXT-FIG. 2.—Festoon-bedded grits; a single outcrop seen from two directions. Above: joint surface perpendicular to direction of current flow. Below: surface parallel to direction of flow. The horizontal line represents 1 metre.

appear to have been deposited in many troughs no more than a few metres wide and a few centimetres in depth. The top of each filling has almost invariably been removed by contemporaneous erosion and the structure which results is of a well-known type in which the beds are festooned in curved laminae concave upwards (see figure in Knight, 1929, reproduced in Pettijohn, 1957, Fig. 58 and Text-figs. 2, 3, and 4 of this paper). This festoon bedding is so clearly exposed that it seems worth while to describe it.

The dimensions of the troughs, as indicated by those of the remnants of the grits laid down in them, remain fairly consistent in any single outcrop. The maximum width is about 6 metres and the majority of troughs are less than 3 metres across; many are less than a metre.

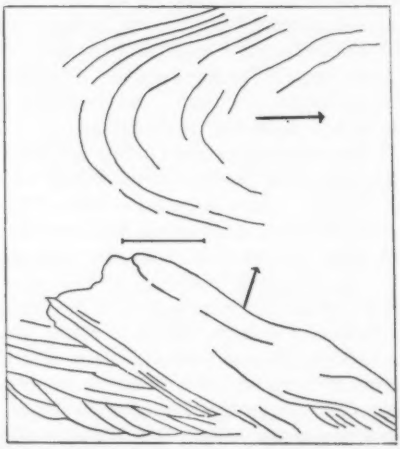
The sides and floor pass smoothly into one another, the sides standing at angles of up to 35° while the floors show gentler gradients ranging from 1 in 5 to 1 in 15. The gradient downstream is not known. We have seen nothing to indicate that collapse of the walls contributed to the formation of the smooth profile; on the contrary, the base of each trough rests on undisturbed deposits and cuts cleanly across their bedding.

The development of the channels seems to have been a necessary preliminary to the deposition of this kind of grit. At localities where grits follow more evenly-bedded rocks of another association, the lowest grits lie in troughs that were scoured out of the underlying sediments, presumably by the swifter currents heralding the coarser deposits. In cross-section, the base of the grits makes a series of smooth curves and adjacent troughs meet in sharp cusp-like ridges. The surface on which deposition took place thus had a fluted form and was perhaps entirely covered by flowing water. Within a grit sequence, the floor of each trough is concave and truncates the underlying structures; its shape is again the result of erosion.

The form of the profiles established during the development of the troughs was maintained as the floor of the trough was built up with new sediment. Where a stream migrated laterally, its profile was preserved by material being laid down on one bank and carried away from the other. In these circumstances, a greater thickness of sediment accumulated on the advancing bank than on the floor of the channel. Individual cross-laminae are commonly 0·5–2·5 cm. thick, but on the flanks of migrating troughs they may reach 20 cm. measured normal to the bedding. In one example, a layer of grit 18 cm. thick on the bank thins to 1 cm. on the floor of the channel 60 cm. away; in another, 9 cm. of grit on the side of a channel is equivalent to 0·5 cm., 15 cm. nearer the centre. The successive deposits left by a stream in its crab-wise progression show that in a general way the curve of the bank built up by the deposition of each new lamina resembles that of banks formed earlier in the development of the same trough. Thus, the three processes of preliminary erosion, deposition, and erosion combined with deposition all work to maintain the forms of the channels. Presumably the channelled type of surface was in equilibrium with the characters of the stream of water and detritus passing over it. A state of balance is also indicated by the repetition through thicknesses of several metres of trough-fillings of broadly similar size and shape without the intervention of any other structural forms. We have seen only a few instances where a parallel-sided bed, or a unit of quite different dimensions, was intercalated in a sequence of festoon-bedded grits. In a few localities, multiple infillings have been noted, a broad trough being packed with smaller lenticles. These

structures might be due to changes in the velocity or load of a current after its initial channel had been cut.

On surfaces parallel to the direction of current flow the cross-laminae dip regularly down-stream and show simple asymptotic bases and truncated tops (Text-fig. 2). Original down-stream dips, measured by reference to the base of the overlying trough, are generally of the order of 10–15° (low-angle cross-laminae, in the terminology of McKee and Weir, 1953). Dips inward from the banks, where the strike of the laminae is virtually parallel to the direction of flow, are often much steeper and reach angles of nearly 35°. Random searches in badly-exposed grits or their metamorphosed equivalents for the greatest original dips as evidence of current directions might therefore prove



TEXT-FIG. 3.—Festoon-bedded grits: a single trough-filling seen in plan (above) and a number of troughs seen in profile (below). The arrows denote the direction of current flow. The horizontal line represents 20 cm.

misleading. The deposits of individual troughs are less clearly defined in longitudinal section than in cross-section, and it is not easy to establish their maximum length. Examples have been seen of channels in which the deposits were built out for at least 3 metres down-stream before being abandoned; obviously, the channels themselves must have been very much longer, since deposition was confined at any one time to a short section of the stream.

Trough fillings exposed in plan are well seen on the old wave-cut platform between Allt an Teanga Odhair and Allt an Eireannaich. The grit units have in plan the lenticular outline characteristic of this

kind of bedding (cf. McKee and Weir, 1953, fig. 2, lower diagram). Individual laminae are spoon-like and more markedly concave from side to side than when viewed in longitudinal section (Text-fig. 3, above). The deposits of neighbouring streams may have built out at roughly the same rate, and this can occasionally be demonstrated where the laminae of adjacent units interdigitate. The form of the inclined beds suggests that in some troughs the rate of lateral migration may have been as great as that at which sediment was built out downstream. We have seen no evidence of meandering; the streams apparently sapped their way sideways without greatly altering their direction.

The original thickness of each trough filling cannot now be established, since the uppermost parts have usually been removed by erosion. The parts that remain range in thickness up to about 30 cm. The average interval separating the bases of successive troughs in several measured outcrops varies from about 5 to 15 cm. This provides a measure of the rate at which troughs were abandoned and appears to be reasonably consistent for at least a few tens of metres along the strike. The average figures for the height of the trough fillings are of the same order as those for the relief of the fluted surfaces on which grit associations rest. This coincidence, and the fact that deposition in small troughs is characteristic of the association, suggests that the water covering the sediment was very shallow. The evidence altogether seems to favour deposition by sheet-flood or shallow braided rivers rather than by current action in a body of standing water.

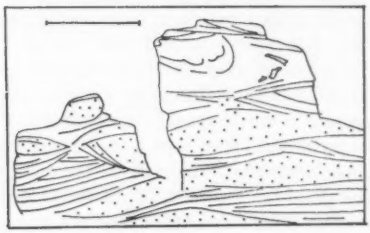
The festoon-bedded grits show considerable variations in grain-size, which are associated with variations in the sedimentary structures. Fine-grained grits generally occupy rather wide channels with flattish profiles. Their cross-laminae are well-defined, are almost invariably concave upwards and show truncated tops. The coarsest grits tend to lie in troughs which are narrower and deeper than the average, suggesting that the stronger the current the more accentuated the fluting of the underlying surface. Coarse grits are often nearly massive and occasionally form lenticular bodies in which the upper surfaces are convex upwards and appear to have undergone no erosion before the deposition of the next trough filling (cf. Text-fig. 4). We have detected no regular variation in grain-size within the contents of a single trough.

*Grit lenses in finer-grained sediments*

Coarse feldspathic grits, lithologically identical with many of the festoon-bedded grits, are found occasionally as discontinuous lenticles, groups of lenticles or irregular bands in thin sequences of finer-grained rocks such as sandstones or siltstones. Good examples can be seen where Allt an Teanga Odhair cuts through the pebbly sea beach, and

on the beach east of Rudha Guail; in both localities the rocks are closely associated with festoon-bedded grits high in the succession. The contact with the grits is usually sharp, but at one locality festoon-bedded grits appear to pass either laterally or upward (the absence of extensive bedding planes makes the distinction difficult) into sandstones with isolated grit lenses.

Coarse pink grits make up to one third or one fifth of the association, the remaining part being composed of green and yellow-weathering, badly-sorted sandstones which may show rather indistinct false bedding and curly bedding. Individual grit lenses range up to about 50 cm.



TEXT-FIG. 4.—Grit lenses in finer-grained rocks: Grits (dotted) forming lenticular bodies in thin-bedded sandstones which locally show curly bedding. The horizontal line represents 50 cm.

in thickness and rarely extend for more than a few metres in any direction. Smaller masses of grit forming lenticles or irregular streaks a few centimetres across, often have diffuse boundaries. Unusually coarse particles, 0·5–1 cm. across, are sometimes scattered on the bedding-planes of the enclosing sandstones or less frequently are sprinkled haphazardly through the body of the rock.

The grit lenses generally rest on concave trough-like surfaces with strong curvature. An example about 3 metres wide thins from 45 cm. at the centre to 12 cm. at the edge. The lenses are frequently convex upward and show a form resulting from deposition and not from later erosion (Text-fig. 4); in this respect they contrast with the majority of festoon-bedded grits already described. Some lenses show no visible internal bedding, and may have been deposited *en masse*. Others show bedding concordant with their margins, and in these it is evident that deposition was most rapid in the centre of the trough. Still others are false-bedded and show truncated tops like the festoon-bedded grits.

The association of grits with finer-grained rocks presumably reflects fluctuating conditions in which the deposition of the more evenly-bedded sandstones was interrupted at intervals by the advent of

stronger currents which scoured the surface and laid down the irregular bodies of grit.

*Arkosic sandstones.*

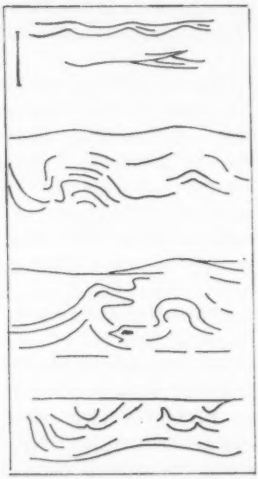
The arkosic sandstone association is second only to the festoon-bedded grits in importance and forms several sequences up to 10 or 15 metres in thickness. It is seen particularly well below high tide mark west of the mouth of Allt Coire Gasgain, and below high tide mark east of Allt an Teanga Odhair. The sandstones form more or less parallel-sided beds and weather to give slabby outcrops distinct from the hummocky outcrops of the grits. Thin partings of brownish-purple mudstone or flaggy sandstone often intervene between the thicker beds.

The sandstone beds range in thickness from about 10 to 60 cm. and the thicker layers can be traced laterally for several tens of metres; they are thus much more extensive than the lenticular beds of grit, and appear to have been laid down on plane surfaces rather than in narrow troughs. Locally there are signs of erosion beneath the beds: underlying shale partings may be transgressed or they may be breached by shallow channels, and disturbed structures (see below) may be smoothed off: but in general the beds follow one another in an orderly sequence.

The internal bedding of the sandstones shows numerous complications. The rocks are frequently false-bedded, occasionally graded and very commonly thrown into complex structures by disturbances taking place soon after deposition. False-bedding laminae generally dip directly down-stream. Festoon-bedding is rare, and where it is developed the troughs are shallower than in the grits. Graded bedding is generally shown only by an upward decrease in the size of the largest particles, the lowest parts of the thicker beds being somewhat gritty in texture; flakes of mudstone, presumably derived from the mudstone partings, may also be seen near the base.

The most distinctive structures of the sandstones are curly-bedding structures formed by post-depositional disturbance. These sometimes produce irregular mounds, ridges and pits on the upper surface of a bed; the relief of the irregularities may reach 30 cm. but is generally a good deal less. In the body of the rock, the rather faint bedding planes show contortions which tend to die out both upward and downward (Text-fig. 5). The shapes of these contortions are complex, but they generally have a number of features in common. One widespread arrangement produces in profile a series of evenly-spaced peaks separated by broader and more rounded hollows (Text-fig. 5, top); in plan, this arrangement may be represented either by an alternation of more or less irregular ridges and troughs, or by roughly circular

mounds and pits. The form of the structures suggests vertical rather than horizontal movement. There is rarely any indication of lateral sliding and we do not regard the contortions as slump structures. One possibility is that the beds were quicksands and were disturbed as water was driven out of them. Such an origin might explain the relative constancy of the spacing of mounds and ridges in many beds. The axes of the more elongated ridges, though they show no very well-defined pattern, tend to follow the same general direction as the troughs of nearby festoon-bedded grits. Of sixteen measurements of such axes, fourteen lie on bearings between 035 and 100, within the range of



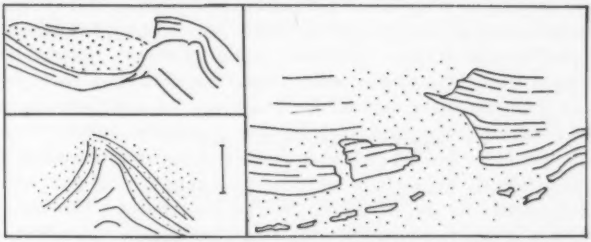
TEXT-FIG. 5.—Arkosic sandstones: curly bedding structures formed by disturbance of the sandstones after deposition. The vertical line represents 30 cm.

variation of the trough directions in the grits. This coincidence strengthens the view that the disturbed structures are not a form of slumping, since slump sheets might be expected to flow down the general gradient and to form structures perpendicular to the trough directions.

Most disturbed sandstones were deformed before the following bed was deposited. Frequently the top of the disturbed bed was planed off and the structures truncated (Text-fig. 5, bottom sketch)—in contrast to the situation in the festoon-bedded grits, the effect of erosion was here to reduce an irregular surface to a smooth one. Where the irregularities were not swept away before the arrival of new sediment (Text-fig. 5, top), one occasionally sees accumulations of coarse

particles in hollows of the surface, or current-bedded sands banked up against ridges and finally overstepping them. At one locality below high tide mark east of Allt an Teanga Odhair, festoon-bedded grits rest directly on a disturbed sandstone and it can be observed that grit lenses occupying hollows in the sandstone surface are larger and thicker than those of the rest of the sequence; it is probable that the first grit-carrying currents were guided by the pre-existing troughs.

Some disturbances in the sandstones, on the other hand, appear to have originated at greater depths and affected more than one bed. Thin mudstones overlying sandstones are in some cases deformed and broken up. They can be seen plastered over the irregular surface of the sandstone, and mudstone fragments are incorporated within the



TEXT-FIG. 6.—Intrusive material from sandstone beds disturbing or breaking through the overlying rocks. The vertical line represents 15 cm.

most violently upheaved material. Other disturbances range through a metre or more of rock and affect several layers of sandstone. Here and there, sand appears to have been injected upwards into breaches in the cover. It may form protrusions between lenticles of overlying grit (Text-fig. 6, lower left) or real intrusions breaking through more regularly bedded rocks (Text-fig. 6, right); the intruding material is structureless and shows no relict bedding but is otherwise not easy to distinguish from the general run of thick-bedded arkosic sandstones. We have seen no structures so well-developed as the sand volcanoes described by Gill and Kuenen (1958), but we have noticed doming of overlying strata and the formation of miniature laccoliths where sand spread out between bedding planes after being forced upward.

*Alternating sandstones, siltstones, and mudstones*

The rocks dealt with here are characterized by the rapid alternation of several rock types and weather to give flaggy-looking outcrops. They are sparsely developed in the lower parts of the Epidotic Grits, but begin to appear between the higher sequence of grits and sandstones. They make the commonest association near the top of the division and pass upwards into the laminated group described later.

They are best seen in the beach and raised cliffs east and north-east of Rudha Guail.

The most noticeable characteristic of the group is the rapid banding which may be so close as to give the rock, in Clough's phrase, " a ribboned appearance ". In one sequence, seventeen purple mudstone films can be counted in 60 cm. of rock. In another, a succession of arkosic sandstone beds contains twenty-five mudstone partings in 15 cm. Where the sandstone beds are thickest (up to 60 cm.), the mudstones intervening are reduced to a few millimetres. Where sandstone beds are only about 5 cm. thick, they are separated by equal or greater thicknesses of siltstone or mudstone.

The thicker beds of grit and arkosic sandstone commonly show false bedding or curly-bedding structures like those already described. The structures of the thin-bedded rocks once more suggest deposition in shallow and perhaps ephemeral bodies of water. Sandstone or siltstone beds occasionally show wavy ripple-bedding throughout, good examples being seen on the beach east of Allt Coire Gasgain where several fine-grained ripple-bedded sandstones some 6 cm. thick are overlain by festoon-bedded grits. Siltstones and mudstones may show ripple-marked surfaces and may contain pockets of grit particles which appear to rest in the hollows of the ripples. The resulting structure appears comparable with that described by Allen from the basal Wadhurst sediments of the Weald (1959, Fig. 5 and pp. 292–3). Graded bedding on a minute scale best seen under the microscope has also been noted; it resembles the structure recorded by Bailey in the Loch na Dal Beds (1955, p. 123).

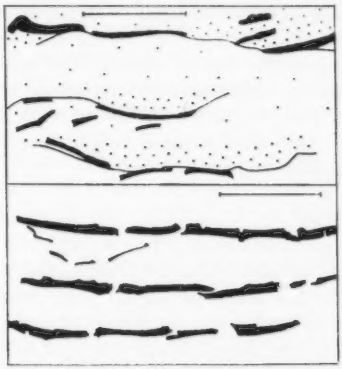
Mudstone partings are seldom more than a centimetre or so thick, but they exhibit some special structures not reproduced in the coarser rocks. The tops of the bands may show in cross-section a curiously fretted and corroded surface which is perhaps due to the flaking-off of a partially dried-out skin. Desiccation cracks occasionally divide the band into polygonal plates about 15 cm. across. The cracks are a centimetre or so wide, reach down several centimetres below the surface and are filled with sandy or gritty material from the overlying bed (Fig. 7, lower sketch). Some mudstone bands, perhaps originally breached by shrinkage, are traversed by wide, flat-bottomed channels filled by material from the bed above. These bands, which are generally those intervening between thick-bedded sandstones, appear in vertical section as lines of undisturbed fragments separated from each other by intervals of 10–30 cm. Detached and tilted flakes may appear in the overlying sandstone (Fig. 7, top).

*Purple and green mudstones*

Clough recorded in the Epidotic Grits occasional bands of purple

or variegated sandy shale unlike any other shales of the Diabaig Group in Skye. We propose to call these rocks mudstones; they are texturally different from the more normal shales higher in the succession. A few mudstone bands 2 or 3 metres thick form independent units in the Grits. Much more common are thin mudstone bands and partings in coarser-grained rocks. These are found in every association except the festoon-bedded grits, where they are extremely rare.

The mudstones range from structureless, blocky types, to finely



TEXT-FIG. 7.—Sedimentary structures in fine-grained rocks. Below: fragmentation of mudstone bands by the development of desiccation cracks. Above: a sequence of sandstone beds, each with a coarser lower part, with intervening fragmented mudstones. Mudstone fragments are incorporated in the sandstones. The horizontal lines represent 10 cm.

banded varieties showing as many as twenty laminae in a centimetre. Under the microscope it can be seen that the lamination is connected with variations in grain-size. In coarse laminae the clastic particles which make up much of the rock have diameters of up to 0·1–0·2 mm. Strictly, the rock is a sandstone. But in the finer layers (which predominate) the general run of particles are less than 0·02 mm. Larger angular fragments up to 0·5 mm. are sparsely scattered through both coarse and fine layers; these may have been deposited with the finer material or have sunk into the mud from coarser layers above. The texture of the mudstones reproduces on a minute scale many features characteristic of the coarse sandstones and grits—the poor sorting, for example, the angularity of the grains and the sprinkling of particles very much larger than those making the bulk of the rock.

Many depositional structures are also on a small scale. Minute graded beds have been noted and very small load casts are developed

where coarser bands rest on the finest mudstones. The occurrence of occasional small lenses of gritty particles, of truncated inclined lamination, and of disconformities and abrupt changes in grain-size records local interruptions in the course of deposition. A structure suggestive of some kind of small-scale ripple formation is seen in certain mudstones which consist of discontinuous lenses a few millimetres long, composed of particles ranging up to 0·3 mm., in a background of finer material. The lamination of the finer rock rises and falls around the lenses which perhaps represent sand laid down in hollows.

Many mudstone partings in banded associations can be traced several metres laterally. Where they can be seen to terminate, their disappearance is generally due to erosion—they sometimes pass into lines of discontinuous fragments before vanishing altogether—and it therefore appears that they originally formed fairly extensive, though very thin, sheets. They were presumably laid down in quiet water on a near-horizontal floor.

*The Laminated Group*

The laminated group lies at the top of the Epidotic Grits and forms a series of passage beds leading to the Loch na Dal Beds. It outcrops in the core of the Lochalsh fold at the point where this structure emerges on the coast, and also on the east side of Rudha Guail and at the west end of the shingle beach near Allt an Teanga Odhair. The rocks consist of flaggy-looking banded siltstones, mudstones, and shales with occasional thicker beds of sandstone and grit. The finest rocks are predominantly grey and in this respect resemble the succeeding Loch na Dal Beds.

The intercalated sandstones and grits form beds up to about 30 cm. thick. The layers of finer-grained rock range from 5 cm. down to a few millimetres; in one outcrop eighty-six laminae were counted in 15 cm. The structures of the finer rocks closely resemble those seen in the sandstone, siltstone, and mudstone association already described. Shaly bands often have irregular, partially eroded tops and detached fragments from them may be incorporated in the overlying bed. Shrinkage cracks divide their surface and small dykelets of silt or sand penetrate the rocks below; these dykelets often trace out erratic courses as if following irregular cracks. Small-scale grading, ripple-marking, and the concentration of grit particles in ripple hollows are common, and resemble the structures in the mixed association already described.

*Structures of the Epidotic Grits in relation to those of the Loch na Dal Beds.*

Although Clough based his sub-division of the Diabaig Group

primarily on lithological criteria, his account of the group showed that some of the sub-divisions were also characterized by particular kinds of sedimentary structures. The Loch na Dal Beds, which follow the Epidotic Grits, are predominantly a group of gritty or sandy shales, with bands of grit and calcareous grit. Clough recorded of these rocks that " The purer shale laminae are mixed in extremely thin alternations with sandy or gritty material . . . This close intermixture of fine and coarse material is a marked feature of the sub-division . . . " (Peach *et al.*, 1907, p. 354–5). He noted also the common occurrence of ripple-marks while Bailey (1955) recorded small-scale graded bedding. All these characteristic structures of the Loch na Dal Beds are of limited occurrence in the Epidotic Grits. As we have seen, ripple-marks, grading and mud-cracks—also found in the Loch na Dal Beds—are seen in the mixed associations near the top of the Epidotic Grits, but are rare in the main part of the sub-division.

Among the coarser rocks, the contrast of sedimentary structures is marked. The lenticular pattern of festoon-bedding so typical of the Epidotic Grits is hardly seen in the Loch na Dal Beds of the type locality. The Loch na Dal grit beds rest either on plane surfaces or on surfaces scoured by isolated erosion channels; the regular fluting seen at the base of grits in the underlying sub-division is not seen. False bedding is common, especially in calcareous grits, but it is predominantly simple or planar cross-stratification in the terminology of McKee and Weir (1953) and not associated with trough structures. Individual grit beds are spread out in extensive sheets instead of forming lenticular bodies; a calcareous grit no more than 20 cm. thick, for example, was traced for 16 metres without dying out. This contrast between the type of bedding in the grits, not lithologically very different from one another, of the two sub-divisions, must reflect some change in the conditions of transport and deposition, possibly the appearance of intermittent sheets of standing water into which flowed currents carrying the sediment.

## IV. Directions of Current Flow

In the festoon-bedded rocks of the Epidotic Grits, the long axes of the troughs give the line along which the currents flowed, while the direction of flow is shown by the consistent dips of cross-laminae seen in longitudinal sections of the trough fillings. Fifty-nine measurements of palaeocurrent directions based on these two criteria were recorded over a distance of 2 km. along the coast-section south-west of the hinge of the Lochalsh fold. All measurements were made on right-way-up rocks dipping at 30° or less, often at only 10–15°. The grits have no cleavage, their clastic particles appear to be undeformed and it is assumed that the sedimentary structures have suffered little

tectonic distortion. It was not thought necessary to make a correction for the tilting they have undergone because experiment showed that the correction only shifted the readings by a degree or so.

The current directions are recorded on Text-fig. 1. As the map shows, they are consistently from the south-west or west and there is a swing towards the west of some 40° in the commonest direction as one goes north-eastward. There is little variation in the directions measured at different levels in single outcrops or adjacent outcrops; if the coast section is divided into two, at about the point where the change in current direction takes place, the readings from each area spread over arcs of about 60°.

The present-day coast-line along which measurements have been made runs almost parallel to the palaeocurrent direction. In the Epidotic Grits north-east of the core of the Lochalsh fold, sedimentary structures are usually too distorted to allow current directions to be measured. About half a kilometre south-west of Port Aslaig, however, on either side of a deep gully marking a Tertiary dyke, moderately well-preserved festoon-bedding is seen in the flat, right-way-up limbs of some small folds. Three trough axes measured at this locality run 072°, 052°, and 088°, the cross-laminae of each trough filling dipping consistently towards the easterly end of the axis. Although the reliability of these measurements is much reduced by the disturbed state of the surrounding rocks they do suggest that the general current direction may have remained much the same in the north-eastern part of the Epidotic Grits outcrop. The trend of the whole outcrop is roughly parallel to that of the currents and it is interesting to speculate on the variations in lithology or thickness which might have been seen if a wider belt were exposed.

## REFERENCES


ALLEN, P., 1959. The Wealden environment : Anglo-Paris basin. *Phil. Trans. Roy. Soc. London, Series B*, ccxlii, 283–346.

BAILEY, E. B., 1950. The structural history of Scotland. *Int. Geol. Congr. Report of 18th Session, Great Britain, 1948*, i, 230–54.

—— 1955. Moine Tectonics and Metamorphism in Skye. *Trans. Edin. Geol. Soc.*, xvi, 93–166.

GILL, W. D. and Ph. H. KUENEN, 1958. Sand volcanoes on slumps in the Carboniferous of County Clare, Ireland. *Quart. Journ. Geol. Soc.*, cxiii, 441–60.

KNIGHT, S. H., 1929. The Fountain and Casper Formations of the Laramie Basin. *Univ. Wyo. Publ. Sci. Geol.*, i, 1–82.

MCKEE, E. D. and G. W. WEIR, 1953. Terminology for Stratification and Cross-stratification in sedimentary rocks. *Bull. Geol. Soc. Amer.*, lxiv, 381–90.

PEACH, B. N. *et al.*, 1907. The Geological Structure of the North-West Highlands of Scotland. *Mem. Geol. Surv. Scotland.*

—— *et al.*, 1910. The Geology of Glenelg, Lochalsh and South-east part of Skye. *Mem. Geol. Surv. Scotland.*

PETTIJOHN, F. J., 1957. *Sedimentary Rocks*. 2nd Ed., New York.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# On the Nature of the Coralline Crag

By D. F. W. Baden-Powell

Abstract

A new fossiliferous section in the Coralline Crag of Suffolk is described, and its fauna is analysed as a clue to the conditions under which these beds were formed ; in particular, the theory that the temperature of the Crag sea was affected by the alternate breaching and closing of land-bridges to the north and south of the North Sea area is considered unnecessary to account for the facts as seen in the field. Further, the Coralline Crag is correlated with the Astian formation of the Mediterranean, and reasons are brought forward to show that the supposed " Boytonian " Zone of the Coralline Crag does in fact not exist.

## The Present State of the Sections

The Crag formations of East Anglia have long been famous as the chief source of our knowledge of the Pliocene and early Pleistocene marine fauna of this country, and therefore give us much valuable information about the changes of climate in this area before the beginning of the Pleistocene Ice Age. The oldest Crag bed known in East Anglia is the Coralline Crag, which rests direct on the Eocene London Clay, and as past geologists have held different opinions about the conditions under which this rock was formed, I undertook, a few years ago, a fresh attempt to solve some of the problems involved. Estimations of the depth of deposition of this Crag have varied from 60 to 1,000 feet ; the climatic conditions during formation have been considered as sub-tropical and alternatively frigid enough for the existence of floating ice ; the percentage of extinct species has been calculated as diversely as 16% and 40% ; and complicated theories of the tilting of East Anglia have been invoked to explain some of the apparent changes of climate represented by the fossil fauna.

The first difficulty in starting this revision was that so many of the best fossiliferous sections which used to be open for the collection of mollusca have long been closed. The main outcrop of these beds is along the hill near Orford and south-west of Aldeburgh, although very small outliers are also known further west, as for instance near Sutton, south-east of Woodbridge : I have not seen the Sutton sections lately, but as far as I know none of them now shows extensive exposures. On the main outcrop, the chief localities for an abundant molluscan fauna used to be concentrated at the south-west end of the ridge between the Butley River and Sudbourne Park. Of these famous sections, the two known as the Broom and the Gomer pits were no longer available thirty years ago (Boswell, 1928, p 24) ; the two sections at Gedgrave Hall were still open ten years later (Boswell, 1938, p. 413), but after that time these pits became very poor for

collecting (Ovey and Pitcher, 1948, p .31) and were completely closed by 1957; some section could be seen in the pit north-west of the Hall in Sudbourne Park in 1947, but it is now almost completely filled in and grassed over, and none of the other pits in the shelly sand along the main outcrop has been reopened.

These depressing facts were somewhat relieved by the discovery of a section with abundant fossils along the lower reaches of the Butley River, two miles south-west of Orford. The exact position is in the river-cliff on the left bank just north of " The Rods " at " The Cliff ", (National Grid reference TM 397486). This section was known to older geologists (Clement Reid, 1890, p. 31), but did not receive as much attention as the nearby Broom, Gomer, and Gedgrave pits, when they were being worked. I first investigated the outcrop in July, 1955, and it was visited by a party of the Geologists' Association in August, 1958 (Baden-Powell and West, 1960, *in the press*). It shows shelly sand about 10 feet thick at the bottom of a high bank overgrown by trees, the sand being only a few feet above present high-water mark in the estuary. The following shells have been identified from this section:

*Anomia sp.*
*Pecten maximus* (Linn.).
E. *Pecten gerardii* Nyst. (c)
*Chlamys opercularis* (Linn.).
*Pectunculus* sp.
*Nucula nucleus* (Linn.).
W. *Cardita corbis* Phil. (a)
E. *Laevicardium decorticatum* (Wood)
*Cyprina islandica* (Linn.)
*Lucina borealis* (Linn.)
*Diplodonta rotundata* (Mont.) (c)
*Lasaea* cf. *rubra* (Mont.)
? *Lepton nitidum* Turt.
E. *Astarte gracilis* Münster (a)
E. *Astarte burtinea* Lajonk. (f.c.)
E. *Astarte omalii* Lajonk.
*Astarte triangularis* (Mont.)
E. *Astarte* cf. *pygmaea* Münster
W. *Woodia digitaria* (Linn.)
*Venus ovata* Penn.
*Cytherea chione* (Linn.)
W. *Cytherea rudis* (Poli)
*Mactra elliptica* (Brown)
*Gari vespertina* (Chem.)
*Corbula gibba* (Olivi)
*Lutraria elliptica* Lam.
? *Donax politus* (Poli)
*Solen ensis* Linn.
cf. *Capulus ungaricus* (Linn.)
cf. *Calyptraea chinensis* (Linn.)
E. *Rissoa obsoleta* Wood.
*Chemnitzia* sp.
E. *Turritella tricarinata* (Brocchi). (f.c.)
E. *Turritella bicincta* Wood.
W. *Turritella incrassata* J. Sow. (f.c.)
E. " *Terebratula grandis* Blum."

E. = Extinct, W. = Warm indicator, (a) = Abundant, (c) = Common, (f.c.) = Fairly common.

The nomenclature used for these shells is as far as possible that of the general lists which have been published in the past, and in particular some " modern improvements " in generic names have been avoided. These specimens, together with some from Sudbourne Park which are mentioned in a later paragraph, are at present in the Department of Geology and Mineralogy in the University Museum at Oxford. Only a few of the identifications in this list are doubtful; *Astarte*

*triangularis* and *Donax politus* were represented by very young specimens, and the relation between *Mactra elliptica* and the extinct form *Mactra ovalis* has not yet been fully worked out; among the gastropods, *Capulus* and *Calyptraea* were only represented by fry, and their identity is uncertain. The specific name in *Terebratula grandis* is used here to conform with the writings of Searles Wood, Clement Reid and others.

*Turritella tricarinata* is a common form of this genus in the Coralline horizon (Baden-Powell, 1955, p. 278) and *Pecten gerardii* and probably *Laevicardium decorticatum* are also typical Coralline Crag forms which seem to be unknown from the Red Crag or any later beds. Other characteristic features are the high number of extinct species, the abundance of warm indicators and the complete lack of evidence (in this collection) of cold conditions.

I have also found the following shells from time to time in the Sudbourne Park pit (immediately north-west of the Hall, grid reference TM 406514):

*Anomia* sp.
*Pecten*
*Chlamys tigrinus* Müller.
*Chlamys opercularis* (Linn.)
*Arca pectunculoides* Scacchi.
*Pectunculus* sp.
*Nucula nucleus* (Linn.)
W. *Cardita senilis* (Lam.)
W. *Cardita corbis* Phil.
E. *Lucina crenulata* Wood
E. *Astarte burtinea* Lajonk
E. *Astarte* ? *parvula* Wood
*Diplodonta* sp.
E. *Astarte gracilis* Münster
E. *Astarte omalii* Lajonk
E. *Astarte* cf. *pygmaea* Münster
*Astarte triangularis* (Mont.)
W. *Woodia digitaria* (Linn.)
*Cytherea chione* (Linn.)
*Mactra elliptica* (Brown)
*Corbula gibba* (Olivi)
*Solen ensis* Linn.
*Saxicava arctica* Linn.
*Capulus* sp.
*Calliostoma* sp.
E. *Turritella tricarinata* (Brocchi)
E. *Turritella biplicata* Bronn

This assemblage is similar to that in the Butley River section, although the two differ in detail. *Cardita senilis* was abundant in one particular layer here, although it was not found in the river cliff; on the other hand *Pecten gerardii* was not found at Sudbourne, but was common by the Butley River. Such differences between one section and the next are the general rule in the Crags, and I do not believe that they indicate any marked difference of age. This pit shows the same mixture of warm indicators with extinct shells which was typical of the Butley River section. In one of the earliest descriptions of the Coralline Crag, Charlesworth (1836, pp. 530–532) emphazised this fact in a different way by pointing out that the fossil shells are as patchy in their distribution as more recent shells are on a modern sea-bottom.

## The Zones in the Coralline Crag

*The problem of the "Boytonian Zone".*—Charlesworth did not believe that the abundance of different fossils in adjacent pits had any zonal significance, but considered the whole of the Coralline Crag to

belong to one series of beds formed without any break in sequence. The early geologists realised a fact which can still be seen in the field to-day: that there are two kinds of Coralline Crag, (1) a shelly sand and (2) a rock-bed made up largely of shell fragments and bryozoa cemented by lime. As already indicated, the distribution of the shelly sand is mostly between the Butley River and Sudbourne Park, whereas the rock-bed outcrops from Sudbourne Park to Aldeburgh. Where the two have been seen together, the sand either underlies the rock-bed or is included in it as soft lumps, and although some geologists originally thought that the two had stratigraphical significance, it was shown by Kendall (1883) and by Harmer (1898, p. 321) that the rock-bed is merely an altered form of the shelly sand, some of the shells having been leached out and the lime redeposited as a cementing material to form the rock.

Prestwich (1868, 1871), however, held a contrary opinion, dividing the Coralline into eight sub-zones, characterized by their fossils. None of these sub-zones was more than 15 feet thick, except for the rock-bed which Prestwich measured as 30 feet (1868, p. 288). Wood and Harmer (1872) and later Harmer (1898, p. 308) disagreed with Prestwich's idea of sub-zones, and no geologist has revived this idea since his time. By the beginning of the present century, the Coralline Crag was accepted as one indivisible whole, and Harmer (1900, p. 752) proposed the name " Gedgravian " for this horizon.

Charlesworth's original distinction between Coralline and Red Crags (1835) has stood the test of time, and is universally accepted to-day. He insisted that some common Coralline species have never been found in the Red or later Crags, and that many of the characteristic shells of the Red have never been found in the Coralline (1835, p. 85). He specially mentioned the shell we now call *Neptunea contraria* as common in the Red Crag and quite unknown in the Coralline (1835, p. 87). Later investigators have naturally changed our detailed knowledge of this subject by new discoveries, but it is still possible to make out a list of extinct species from the Coralline which have not yet been found in the Red Crag or any later beds, and the most important of these seem to be:—

*Pecten princeps* Sow.
*Pecten gerardii* Nyst.
? *Laevicardium decorticatum* (Wood)
*Woodia excurrens* Wood
*Astarte parvula* Wood
*Lucina crenulata* Wood
*Verticordia cardiiformis* Wood
*Gibbula ditropis* (Wood)
*Rissoa pulchella* Philippi
*Turritella tricarinata* (Brocchi)
*Scalaria frondosa* J. Sow.
*Admete reedii* Bell
*Adeorbis tricarinatus* Wood
*Velutina virgata* Wood

So far as our present knowledge goes, these species can be considered as restricted to the Coralline Crag in England. The most common forms known in the Red Crag which are unknown in the Coralline

include *Tellina praetenuis* Woodward, *Mactra constricta* Wood, *Purpura tetragona* Sow., *Neptunea antiqua* (Linn.) and as already mentioned, *Neptunea contraria* (Linn.). In addition to all this palaeontological evidence, there is the well-known slight unconformity between the Coralline and Red Crags at Sutton, south-east of Woodbridge.

In the face of all these facts, it is most surprising that Alfred Bell (1911, p. 296) claimed to have discovered a bed with mixed Red and Coralline faunas which he proposed to name the Boytonian, after the site at which the find was made, in shallow trenches dug for phosphatic nodules at a low level near the Boyton Marshes, west of the mouth of the Butley River. From all accounts, the total thickness of Crag in this and similar excavations was only about 4 feet, and Bell claimed that at the place where he collected the fossils there was about 2 ft. 6 in. of Red Crag resting on 1 ft. 6 in. of Coralline, (see Harmer, 1898, p. 333, footnote 3). Bell gave a long list of shells from his Boyton Zone (1911, pp. 302–305), which included some exclusively Coralline species and others not known earlier than the Red Crag. Bell considered this as a passage-bed between the two Crags, and claimed to have seen the " same conditions " at Ramsholt, Waldringfield, Walton, and Bawdsey sections. Harmer had been critical of the Boyton sections at one time, but eventually adopted Bell's idea and agreed that the " Boytonian " is intermediate in fauna between the Coralline and the Red Crag (Harmer, 1914–1925, pp. 4, 5, 62, and 492), and in fact classified it as an upper zone of the Coralline younger than the Gedgravian, (1914–1925, p. 5).

The explanation of this anomaly is probably to be found in Wood's record (1879, p. 3, footnote 1) that the shells from the two Crags were shovelled out together from under water in a trench by the " coprolite " diggers; again (1882, p. 11), that the " shells of both formations " became intermingled while being dug out. Later, Harmer (1898, p. 333) said that the workmen mixed the material brought up on their spades to such an extent that it was impossible to say which formation the shells came from, and he mentioned *Tellina praetenuis*, *Neptunea contraria* and *Neptunea antiqua* as never having been found in the Coralline Crag anywhere else. Although Harmer eventually came round to Bell's point of view, no other palaeontologist, so far as I know, has accepted the Boytonian Zone, and apparently Boswell was suspicious of it when he wrote in the Geological Survey Memoir (Woodbridge, 1928, p. 21). I consider that the supposed mixture of Red and Coralline forms is an impossible one from any single deposit. This is even more obvious when one realises that the Coralline Crag under the Boyton Marshes is, according to its level, from the base of that formation, and the Red Crag shells from this site are of Newbourn

or Butley type, with the shell *Mactra constricta* which is unknown in the lower part of the Red Crag. As the Butleyan is the uppermost division of the Red Crag, we are otherwise asked to believe that the base of the Coralline Crag can have the same fauna as the top of the Red Crag. The mixture of two faunas while being dug out, accepted by most former geologists, seems to me to be the most likely explanation.

Unfortunately, it would be very difficult to prove this now at Boyton itself, partly because it is doubtful whether anyone living knows where the sections were, and also because the material would have to be dug or pumped up from under water. If a " Boyton fauna " is ever found in any Crag section in the future, it should be looked for in the base of the Waltonian Crag, and, by definition, such a bed would certainly be part of the Red Crag series, and younger than any Coralline Crag.

*The Astian age of the Coralline Crag.*—If this Crag is accepted as one indivisible zone, it seems that Harmer's name Gedgravian becomes unnecessary, especially if we can correlate it with some definite zone recognized elsewhere. Bell (1911, p. 290) pointed out that the Coralline is later than the Pliocene Lenham Beds on the North Downs in Kent, as that deposit has the well-known *Arca diluvii* fauna which has never been found in the Suffolk Crag. This was Harmer's opinion also (Harmer, 1898, p. 308), and there is therefore no other known Pliocene bed in Britain with which the Coralline Crag can be compared, apart from the St. Erth clay in Cornwall, the age of which is uncertain. If we turn to the classical marine beds of the Mediterranean area, it can be seen at once that the Astian is the formation which has most in common with the Coralline Crag. Both these horizons have *Turritella tricarinata* as a typical species rather than the later forms of this shell, *pliorecens* and *communis*: both have a large number of extinct species associated with a predominantly warm fauna, and both precede the sudden appearance of *Neptunea contraria* which is found for the first time in the Calabrian beds and the Red Crag respectively; both also precede the first appearance in quantity of the cold indicators which are so typical of the Calabrian and of the Red Crag. As a matter of detail, it should be mentioned that rare cold indicators have been reported from time to time from the Coralline Crag, but most of them, like *Trichotropis borealis* and *Buccinopsis dalei*, are still living in British waters as well as farther north, and have only a slightly cold tendency. In matters of this kind, one should remember Harmer's excellent advice (1895, p. 27) that although rarities are occasionally important, it is the common shells rather than the rare ones which give to a deposit its character; in this case I have never yet found a cold indicator in the Coralline Crag, although warm indicators like *Cardita corbis* occur in abundance in a section like that along the Butley River. To me there seems to be no doubt that the Coralline

Crag can be dated as Astian, as previously noted (Baden-Powell, 1955, pp. 272, 273, and 285).

Estimates of the climatic equivalent of the Coralline Crag would not be complete without a reference to the boulder of porphyry which Prestwich described as coming from the Coralline Crag and as representing floating ice at this stage (Prestwich, 1871, pp. 134–135). Harmer (1896, p. 30) thought that this one specimen was not necessarily introduced by ice, and later (1898, p. 346) described it as not having been found in the Crag itself, but in the basal bed: in fact, he thought that it could have got onto a land-surface before the area was submerged by the Crag sea. Bell (1911, p. 293) agreed with this interpretation.

## The Depth of the Coralline Crag Sea

The present height of the Coralline Crag above sea-level and the original amount of submergence and method of formation of this deposit are of importance in relation to the supposed crustal movements which have been suspected in this area (Longfield, 1932 and 1933). The present height of the top of the Coralline in the main Gedgrave-Orford outcrop is about 40 feet O.D., though it naturally varies by a few feet in places. Harmer (1898, pp. 329–331) discovered by putting down a number of boreholes that the base of the Coralline Crag resting on London Clay slopes gently north-eastward at a gradient of about 6–8 feet per mile. There seems no reason to suppose that this represents anything more than an undisturbed sea-bottom gradient under the original Crag Sea.

There has been much difference of opinion about the depth of deposition of the Coralline Crag. Godwin-Austen (1868, p. 476) estimated that the top of the Crag at 40 feet O.D. was formed under some 40 fathoms of water, giving a difference of about 300 feet from present sea-level: Prestwich considered a submergence of about 1,000 feet more likely (1871, p. 135): both Wood and Harmer (1872, p. iv) and Clement Reid (1890, p. 39) thought that Prestwich's estimate was excessive, and Harmer (1898, p. 244) pointed out that if this Crag sea-level had really been 1,000 feet above present sea-level, the greater part of eastern England would have been submerged, and there is no evidence of this having happened. Harmer thought a depth of 15–50 fathoms of water to be a fair estimate, though Monckton (in Harmer, 1902, p. 483) judged the depth of deposition to be 10 fathoms. As no shore-line belonging to this stage is known, it is difficult to judge between these alternatives but my own impression of this obviously shallow-water formation is that 100–200 feet O.D. would be much nearer the height of this Crag sea-level than Prestwich's 1,000 feet.

The oblique bedding which is seen so well in some sections has been

taken as evidence of off-shore sandbanks rather than a beach formation. Clement Reid (1890, p. 36) suggested that the currents could move the sand grade material because cylindrical Bryozoa were found to be more worn than branching forms. Harmer (1898, p. 327 and 1914–1925, pp. 489–490) agreed that the material was arranged by current action, and thought this responsible for some sorting of the shells according to size which is seen in certain sections. Both these geologists considered the main Coralline Crag outcrop to have originated as an off-shore sandbank, probably more or less parallel to the Crag coast-line like the sandbanks forming here to-day which are parallel to the present coast. Harmer (1898, p. 348) also made an interesting comparison with the deposition of shells on the Turbot Bank in the Irish Sea at the present day, and (1898, pp. 349–350) pointed out that if the present form of the main Coralline Crag outcrop is a depositional form, later erosion by the Red Crag sea must have had little effect on its outline. These details again suggest a Crag sea-level of only about 100–200 feet O.D.

*Evidence of the Coralline Crag on crustal movement.*—These estimates of former sea-level do not by themselves give any information about subsequent tilting movements, especially as there are no other known outcrops of Coralline Crag in Britain with which they can be compared. The height of the Lenham Beds, in Kent, at about 600 feet cannot be taken to indicate any tilting between the North Downs and the outcrop of the Coralline Crag, if we are correct in dating the Lenham Beds as considerably older than the Coralline Crag. The evidence of the age of the St. Erth Clay in Cornwall is too contradictory for its height to be considered here.

Three main opinions have been advanced about crustal movements which are believed to have affected this area. The first of these referred to the Crag Series as a whole, and originated with Wood (1872, pp. 193–194), who suggested that the increase of cold conditions during the formation of the Red Crag as compared with the warm climate during the time of the Coralline could be explained by the formation of a land-barrier cutting off the North Sea basin from the south (but open to the north), and that the return to warmer conditions in the much later formation which we now know as the Corton Beds (Wood's " Middle Glacial ") could be due to the destruction of the southern barrier. Harmer (1896, p. 30) supported Wood's theory by suggesting that the great rarity of cold indicators in the Coralline Crag showed that the North Sea basin was not open to the north at that time. At a later date Harmer (1914–1925, p. 487) suggested that the colder invasion of mollusca at the beginning of Red Crag times could have been let in to the North Sea basin by " subsidence " in the north, similar to the northward tilt which Harmer believed to have been

proved in Holland and Belgium by the evidence from deep boreholes. In other words, he explained the climatic changes in terms of a northward tilt of the North Sea basin.

A very different opinion has been expressed by Boswell (1915), who considered that an anticline has been forming gradually in south Suffolk, with its axis running south-eastward to the present coast at the mouths of the rivers Colne, Stour, and Gipping. The main outcrop of the Coralline Crag lies on the north-east limb of the anticline, and at first sight the north-eastward gradient of the base of the Coralline Crag which was proved by Harmer's boreholes might seem to support Boswell's suggestion. However, the gradient of the apparent dip in the crag is so gentle that it might well be simply the original slope of the sea-floor, and the nature of the main Coralline Crag outcrop neither supports nor disproves Boswell's hypothesis. The third suggestion was made by Longfield (1932 and 1933), who described the results of relevelling by the Ordnance Survey, which suggested that there had been a subsidence of the Essex and Suffolk coasts at least since about the year 1860, and that this subsidence was confirmed as a reality by an analysis of the recordings by the tidal gauge at Felixstowe. The general results of Longfield's work suggest that there has been a tilt to the south-east with its maximum effect at Harwich and Felixstowe; unfortunately the outcrop of the Coralline Crag is not extensive enough to show this effect.

No final solution of the problem can be attempted here, but it is at least interesting to see how far the nature of the Coralline Crag can contribute answers to the questions raised. It can be said immediately that Wood and Harmer's northerly tilt is by no means necessary to explain the climatic changes shown by the shells. It has been shown (Baden-Powell, 1955) that the climatic changes which took place in the Pliocene and Pleistocene Mediterranean were almost identical with those taking place in Britain; the changes in the Crag faunas could equally and more simply be explained by shifts in the climatic belts on western Europe than by Wood and Harmer's tilting. Furthermore, the distribution of the Coralline Crag cannot be held either to support or to disprove Longfield's tilting or Boswell's anticline.

## REFERENCES

BADEN-POWELL, D. F. W., 1955. The correlation of the Pliocene and Pleistocene marine beds of Britain and the Mediterranean. *Geol. Mag.*, lxvi, 271–92.

BADEN-POWELL, D. F. W., and R. G. WEST, 1959. Summer Field Meeting in East Anglia, 14–24 August, 1958. (In the press).

BELL, A., 1911. On the zones of the East Anglian Crags. *Journ. Ipswich District F.C.*, iii, 5–17.

BELL, A., 1911. On the zonal stratification of the eastern British Pliocenes. *Essex Nat.*, xvi, 289–305.

BOSWELL, P. G. H., 1915. Differential movement in East Anglia in Tertiary times. *Geol. Mag.*, lii, 198–206.

BOSWELL, P. G. H., 1928. The geology of the country round Woodbridge, Felixstowe and Orford. *Mem. Geol. Surv.*

BOSWELL, P. G. H., 1938. Whitsun Field Meeting, 3rd June, 1938. Ipswich District. *Proc. Geol. Assoc.*, xlix, 410–14.

CHARLESWORTH, E., 1835. Crag-formation and its organic remains; with a view to establish a division of the Tertiary strata overlying the London Clay in Suffolk. *Phil. Mag.*, (3), vii, 81–94 and 1836, (3), viii, 529–38.

DALTON, W. H., and W. WHITAKER, 1886. The geology of the country around Aldborough, Framlingham, Orford, and Woodbridge. *Mem. Geol. Surv.*

GODWIN-AUSTEN, R. A. C., 1868. Presidential address to Geology Section, British Association, Norwich, 1868. *Geol. Mag.*, v, 469–80.

HARMER, F. W., 1896. The southern character of the molluscan fauna of the Coralline Crag tested by an analysis of its more abundant and characteristic species. *Geol. Mag.*, xxxiii, 27–41.

HARMER, F. W., 1898. The Pliocene deposits of the east of England: the Lenham Beds and the Coralline Crag. *Quart. Journ. Geol. Soc.*, liv, 308–54.

HARMER, F. W., 1900. On a proposed new classification of the Pliocene deposits of the east of England. *Rep. Brit. Assoc.*, for 1899, Dover, 751–53.

HARMER, F. W., 1902. A sketch of the later Tertiary history of East Anglia. *Proc. Geol. Assoc.*, xvii, 416–79.

HARMER, F. W., 1914–1925. The Pliocene mollusca of Great Britain. *Mon. Pal. Soc.*

KENDALL, P. F., 1883. On the dissolution of aragonite shells in the Coralline Crag. *Geol. Mag.*, xx, 497–99.

LONGFIELD, T. E., 1933. Subsidence of London. *Proc. Geol. Soc. Lond.*, 1260, 73–9.

LONGFIELD, T. E., 1932. The subsidence of London. *Ordnance Survey Professional papers*, 14.

OVEY, C. D., and PITCHER, W. S., 1949. Observations on the geology of East Suffolk. *Proc. Geol. Assoc.*, lix, 23–34.

PRESTWICH, J., 1868. On the structure of the Crag-beds of Norfolk and Suffolk, Part I. Coralline Crag. *Quart. Journ. Geol. Soc.*, xxvii, 115–46.

REID CLEMENT, 1890. The Pliocene deposits of Britain. *Mem. Geol. Surv.*

WOOD, S. V., 1848–1882. The Crag Mollusca. *Mon. Pal. Soc.*, 1st Suppl., 1872, 2nd Suppl., 1879, 3rd Suppl., 1882.

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# A Fine Air-Heave Structure from the Old Red Sandstone of Lanarkshire, Scotland

By W. D. Ian Rolfe

(PLATE V)

Abstract

Air-heave structures have previously been described from marine lagoonal deposits, both from present day and ancient sediments. This paper records the find of such structures in playa sediments from the Scottish Old Red—perhaps the first record of such structures from non-marine sediments in the geological column. It is suggested that the structures were formed on the beaches of " Lake Caledonia ", " during a storm, seich, or a heavy rainfall ".

## I. Introduction

Since what must have been their first description in this magazine in 1884 (Reade), air-heave structures have excited occasional attention. Emery concluded that " an ancient sandstone containing an abundance of these features on most of the laminae was probably deposited as a marine beach. If the features are rare, or present on only a few laminae, they could have been formed during a storm, a seich, or a heavy rainfall on a lacustrine beach " (1945, p. 49). His paper contains an exhaustive treatment of the subject based upon ample field experience. It only remained for Stewart to demonstrate the dynamics of the mode of formation of the structures by means of laboratory experiments (1956). The present paper records what is thought to be the first truly non-lagoonal occurrence of an air-heave structure (as they have been termed by Stewart, 1956, p. 159), from the geological column. Bibliographies containing the chief records of marine occurrences of air-heave structures can be found in van Straaten (1959, pp. 204–5, 214–6) and Stewart (1956, pp. 159–161).

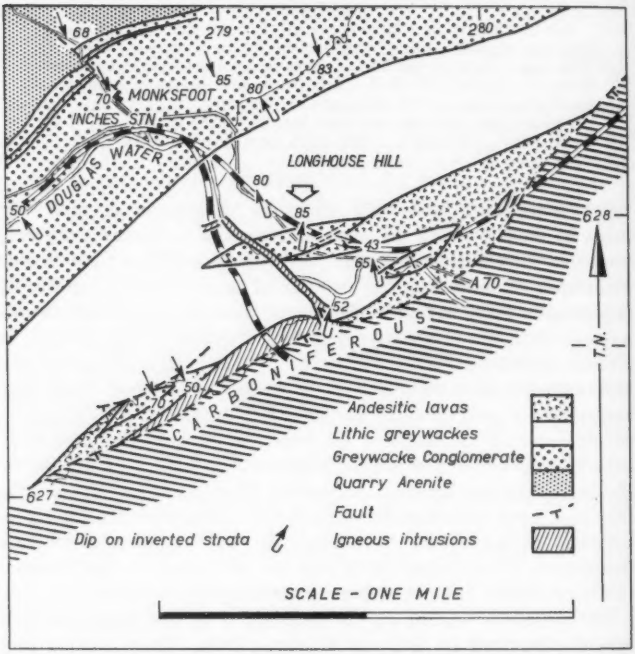
The structures should not be confused with the sand volcanoes recently described by Gill and Kuenen (1958). Despite some very superficial similarities these are a fundamentally different form of structure. Pit-and-mound structures (Shrock 1948, pp. 132–6) are readily distinguished by their relatively minute size.

## II. Occurrence

The specimen was collected in 1956 while engaged on preliminary mapping of the Hagshaw Hills Silurian inlier in the Earl of Home's estates. Details of that inlier have yet to be published, but the specimen can be described as coming from the overturned south-eastern limb of the anticline. It was found in the north-eastern face of Inches railway cutting, 1,000 feet south-east of the bridge carrying the railway over the A. 70 Edinburgh–Ayr road, four miles south-west of Douglas in Lanarkshire, Scotland (Geological Survey 1 inch Scottish Sheet

23, Grid References O.S. 1 inch Sheet NS 793281); see Text-fig. 1. Plate V, fig. 1 shows that the collected specimen is only one of a "nest" of five such structures affecting the same bedding planes.

From the general structure of the area, confirmed by local current and scour-and-fill bedding, the stratum containing the structure was




TEXT-FIG. 1—Part of the south-easterly overfolded limb of the Hagshaw Hills anticline, showing the basal Old Red Sandstone succession. The air-heave structure was obtained from the locality at the head of the 85° dip arrow, indicated by the larger arrow in the centre of the map.

known to be overturned, dipping 85° at 010° True North, i.e., overturned 5° to the north-east. It lies approximately 1,300 feet measured stratigraphically, above the top of the Greywacke Conglomerate, taken as the local base of the Old Red Sandstone.

The age of the enclosing strata is extremely dubious. They can only be dated by poor homology with the *Cephalaspis traquairi* bearing arenites of the Penning Hill quarries, Changue Burn, Tulloch Hill, near Lanfine in the Sorn district of Ayrshire (*v.* Armstrong *et al.* 1876, p. 30, Hunter 1885, pp. 161–8, Geikie 1872, p. 8 and MacGregor 1930,

pp. 19–22), or the unverifiable *C. glottensis* bearing beds of Lesmahagow (Powrie 1885, p. 163). Stensiö has dated the former as Dittonian or Downtonian (1932, p. 203, King 1925, p. 383).

The occurrence of typical Old Red andesitic lavas only 400 feet higher up in the succession cannot be used as positive evidence, since a minor flow is also found in the underlying Greywacke Conglomerate.

## III. Description

All of Stewart's criteria erected for the recognition of air-heave structures apply to this structure (1956, p. 159). The essential verticality is strikingly developed (Plate V, fig. 2) and closely resembles a laboratory structure illustrated by his Fig. 4d.

The up-doming caused by the structure has a diameter of 20 cms. and a maximum height of 3·5 cms. An unusual feature of the specimen is the oval nature of the occluded pipe, its long diameter being between 2·5 and 3·3 times greater than the short. These dimensions are very slightly larger than those quoted by Emery (1945, pp. 39–40), but well within the limits suggested by Stewart (1956, pp. 154, 159).

The sediment is well bedded and the individual laminae, up to 1 cm. in thickness, become attenuated over the dome. A reduction to ½ or even ⅓ the thickness of the undisturbed laminae can be measured in the vertical limb of the structure. Over the dome of the structure individual laminae may be almost completely cut out, leaving only a wafer-thin membrane of sediment.

In thin section the rock is seen to be a medium-grained arenite, the majority of the extremely angular particles falling between 0·144 and 0·346 mms. in diameter. Despite its greyish red purple colouration (Rock Colour Chart 1951, 5 RP 4:2), the rock must be termed a greywacke, and in view of the predominance of sedimentary rock particles falls well inside Pettijohn's lithic greywacke category (1957, p. 291). Such non-marine greywackes are rare, but not unknown (*v.* Pettijohn 1957, pp. 288–90. 309 and 314).

## IV. Discussion

The obvious occurrence of current and scour-and-fill bedding, together with well developed clay-galling, scoured pellet-beds and sun-cracking, all characteristic desiccation phenomena, leaves no doubt that the enclosing arenites are of typical "Old Red" origin. There seems to be no reason to suspect their being of marine origin, although the absence of any fauna prevents complete certainty. The wedges of conglomerate as newly mapped (Text-fig. 1) would thus appear to be true fan-glomerates. The associated lava flows also show no evidence of extrusion under submarine conditions.

Macgregor and MacGregor's excellent summary of conditions for

deposition of the Midland Valley Lower Old Red Sandstone (1948, pp. 21–2) will suffice for this area too, unless quite radical changes in the palaeo-geography are invoked. In this connection it is interesting to note Poborski's notification (1954, p. 995) of typical desiccation phenomena associated with what Stewart (1956, p. 160) interprets as air-heave structures. There the sediments were known to be of marine origin, however, and thus could be ascribed to a shallow water lagoonal environment. In the absence of good evidence for marine deposition, with the presence of typical sub-aerial lavas and boulder fans, the more or less desert reconstruction must be preserved for this case.

This occurrence thus vindicates the prophecy that Emery made after observing recent structures in a beach of the lacustrine Salton Sea, that air-heave structures might eventually be found in ancient lacustrine sediments (1945, pp. 45, 49). The fact that only one such " nest " of structures has been found despite careful examination of some thousands of feet of sediment, poorly exposed over a total area of at least six square miles, perhaps also bears out Emery's deduction that they might well be rare in such non-marine environments.

## V. REFERENCES


ARMSTRONG, J., J. YOUNG and D. ROBERTSON. 1876. *Calatogue of Western Scottish Fossils.* Glasgow.

EMERY, K. O., 1945. Entrapment of Air in Beach Sand. *J. Sed. Petr., xv,* 39–49.

GEIKIE, J., 1872. Explanation of Sheet 22. *Mem. Geol. Surv. Scot.*

GILL, W. D. and P. H. KUENEN, 1958. Sand volcanoes on slumps in the Carboniferous of County Clare, Ireland. *Quart. J. Geol. Soc. Lond., cxiii.* 441–457.

HUNTER, J. R. S., 1885. The Old Red Sandstone of Lanarkshire. *Trans. Geol. Soc. Glasg., viii,* 161–8.

KING, W. W., 1925. Notes on the " Old Red Sandstone " of Shropshire. *Proc. Geol. Ass., Lond., xxxvi,* 383–9.

MACGREGOR, A. G., 1930. *In* The Geology of North Ayrshire. (Explanation of One-Inch Sheet 22), 2nd ed. *Mem. Geol. Surv. Scot.*, 19–22, 33–7.

MACGREGOR, M. and A. G. MACGREGOR, 1948. *British Regional Geology: The Midland Valley of Scotland,* 2nd ed. Edinburgh.

PETTIJOHN, F. J., 1957. *Sedimentary Rocks,* 2nd ed. New York

POBORSKI, S. J., 1954. Virgin Formation (Triassic) of the St. George, Utah, Area. *Bull. Geol. Soc. Amer., lxv,* 971–1006.

POWRIE, J., 1885. Footnote to *The Old Red Sandstone of Lanarkshire* by J. R. S. Hunter. *Trans. Geol. Soc. Glasg., viii,* 163.

READE, T. MELLARD, 1884. Miniature Domes in Sand. *Geol. Mag., xxi,* 20–2.

SHROCK, R. R., 1948. *Sequence in layered rocks.* New York.

STENSIÖ, E. A., 1932. *The Cephalaspids of Great Britain.* British Museum (Natural History).

STEWART, HARRIS B., 1956. Contorted Sediments in Modern Coastal Lagoon Explained by Laboratory Experiments. *Bull. Amer. Ass. Petrol. Geol., xi,* 153–161.

STRAATEN, L. M. J. U. VAN., 1959. Minor structures of some recent littoral and neritic sediments. *Geol. en Mijnb., xxi,* 197–216.


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FIG. 1.—Overturned air-heave structures *in situ* in Inches railway cutting. The bedding laminae dip at 85° into the plane of the photograph and thus only the top surfaces of the domes and occluded pipes can be seen. The hammer shaft is one foot in length.

FIG. 2.—Vertical section of the specimen collected from the above locality. The structure can be seen centre left at the foot of fig. 1 above.

AIR-HEAVE STRUCTURE IN OLD RED SANDSTONE.

*Facing p.* 136.

# New Hystrichospheres from the Upper Jurassic of Dorset

By W. A. S. Sarjeant

(PLATE VI)

Summary

From assemblages of Upper Jurassic organic-shelled microplankton from Dorset are described five new species of hystrichospheres. Of these, two are attributed to a new genus, *Polystephanosphaera;* one new species of the genus *Hystrichosphaeridium*, and two of the genus *Baltisphaeridium* are also described.

## I. Introduction

In the course of study of assemblages of fossil organic-shelled microplankton from horizons in the Upper Jurassic of Dorset, a number of hystrichospheres of types not previously described have been encountered. The horizons studied range in age from Middle Callovian to Lower Oxfordian. During this study, the finding of comparable forms occasioned re-study of Downie's Upper Kimmeridgian material from Dorset, and on this basis a further new species is erected. All type specimens of species described are now in the collection of the Micropalaeontology Laboratory, Department of Geology, University of Sheffield.

## II. Systematic Description of Species

### Order HYSTRICHOSPHAERIDIA

### Family HYSTRICHOSPHAERIDAE

Genus Hystrichosphaeridium Deflandre 1937 emend. Eisenack 1958

*Hystrichosphaeridium cribrotubiferum* sp. nov.

Plate VI, figs. 2–3; Text-fig. 1

*Diagnosis.*—A species of *Hystrichosphaeridium* having a spheroidal shell bearing a moderate number (less than forty) of tubular appendages of variable thickness, arising from broadened bases. The bases sometimes have root-like extensions. The open ends of the appendages give rise to fibrils of very variable length, number and direction: these fibrils sometimes bifurcate. The walls of the tubes are perforate, the perforations being of very constant diameter and distance apart in any particular tube and arranged in rows along the tube's length. Adjacent perforations in different rows show an arrangement in quincunx in relation to one another.

*Description.*—The shell is yellowish in colour and devoid of surface ornament. All specimens seen were in some degree obscured by extraneous organic material caught up by their processes.

*Type Specimen.*—WF 108/13/3 (Plate VI, fig. 2; Text-fig. 1). *Dimensions.* Type: overall diameter 75 $\mu$, shell diameter 46 $\mu$,

processes *c.* 16 $\mu$ long and 1·5 to 3·5 $\mu$ broad. The range of overall diameters observed was from 60 to 80 $\mu$.

*Remarks.*—Eight specimens seen in an assemblage from the lowest level of the Oxford Clay (*Cardioceras cordatum* Zone) exposed above the shingle in Furzy Cliff, Weymouth (grid reference 698810).

The possession of perforations in the tubes, a feature observable only at higher magnification, distinguishes them from all known

TEXT-FIG. 1.—*Hystrichosphaeridium cribrotubiferum* sp. nov., showing the detailed structure of the processes. The specimen figured is the type, WF 108/13/3. × 600.

species of *Hystrichosphaeridium*. Of existing species, the most closely comparable, is *H. salpingophorum* (Deflandre) also present at this horizon: this latter species also differs in that fibrils at the tube mouth extend as raised striations down the walls of the tube and out onto the tube surface as rootlets, whereas the tubes of *H. cribrotubiferum* sp. nov. lack striations.

## Genus BALTISPHAERIDIUM Eisenack 1958

### *Baltisphaeridium downiei* sp. nov.

Downie, 1957, *Quart. Journ. Geol. Soc.*, Pl. xx, fig. 10; Text-fig. 4c.
SYNONYMY: *Hystrichosphaeridium pattei* Downie 1957 *non* Valensi 1948

*Diagnosis.*—A species of *Baltisphaeridium* having a spheroidal to ovoidal shell densely covered by very short spines, knobbed or briefly bifurcate, sometimes connected by low ridges on the shell surface. The spines are in number such that 70 to 90 are seen around the shell periphery: their length is of the order of one-thirtieth the longest shell diameter.

*Type Specimen.*—KL 11/15/111/580, figured by Downie, 1957.
*Dimensions.*—Type specimen: overall long diameter 50 $\mu$, short diameter 45 $\mu$ (slightly damaged). Spines 1 to 1·5 $\mu$ in length. Range: overall diameters 32 to 50 $\mu$.

*Remarks.*—Over 90 specimens of this species were obtained by Dr. Charles Downie, from the Upper Kimmeridge Clay (*Subplanites* Zone) of Norfolk and Dorset, in which assemblages it proved the most common hystrichosphere.

They were originally attributed to *Baltisphaeridium pattei* (Valensi,

TEXT-FIG. 2.—*Baltisphaeridium lumectum* sp. nov. The specimen figured is the type, O 128/15/22. × 600.

1948) on the basis of the relative proportions of shell and processes and the presence of ridges linking some spine bases. However, examination of Downie's material shows that his specimens lack the network of crudely polygonal plates on the shell surface, described by Valensi as characteristic of the species. The spine lengths quoted here are the correct ones; those originally quoted were incorrect.

*Baltisphaeridium downiei* sp. nov. differs from *Baltisphaeridium fimbriatum* (White, 1842) of the Cretaceous of England, and from *Baltisphaeridium* cf. *fimbriatum* (White) Sarjeant, 1960, in the relative length of its processes, around one-thirtieth instead of one-tenth the shell diameter.

*Baltisphaeridium lumectum* sp. nov.
Plate VI, fig. 1; Text-fig. 2

*Diagnosis.*—A species of *Baltisphaeridium* having an unornamented spheroidal shell, from which arise slender processes, simple, bifurcate or trifurcate, usually curved in some degree. The number of processes is such that 35 to 40 are seen around the shell periphery: their length is greater than two-thirds the shell diameter.

*Description.*—Shell dark yellowish brown in colour. The processes are of constant length. Near their tips they frequently bifurcate or trifurcate, the resultant branches not being of constant length on an individual process or between processes: equally frequently, however, they are simple.

*Type Specimen.*—O 128/15/22 (Plate VI, fig. 1; Text-fig. 2).

*Dimensions.* Type specimen: overall diameter 60 $\mu$, diameter of shell 25 $\mu$, spines *c.* 17 $\mu$ long. Range: overall diameters 45 to 65 $\mu$.

*Remarks.*—Thirty-seven specimens seen in an assemblage from an exposure of the Ringstead Waxy Clay (top of *Epipeltoceras bimammatum* Zone) 1 foot below the base of the Ringstead Coral Bed at the top of the cliffs at Osmington Mills, Dorset (grid reference 817736). This is the most frequent hystrichosphere in this assemblage.

In the combination of form, length, and number of the spines, *Baltisphaeridium lumectum* sp. nov. differs from all other species described. *Baltisphaeridium multifurcatum* (Deflandre, 1937), from the Cretaceous of France, has processes similar in form but much shorter (less than one-quarter the shell diameter): in addition, the shell surface of this species is covered by a " vermicular ornamentation " lacking in *B. lumectum*. The specimens attributed to *Baltisphaeridium polytrichum* (Valensi, 1947) by Downie, 1957, from the Upper Kimmeridgian of Dorset, have simple or bifurcate processes less than half the shell diameter in length, but similar in number: their resemblance to *B. lumectum* is such that they would perhaps be better named *Baltisphaeridium* sp. aff. *lumectum* than referred to *B. polytrichum*, a species having entirely simple spines in much greater density (Valensi, 1947, 1953).

### Genus Polystephanosphaera nov.

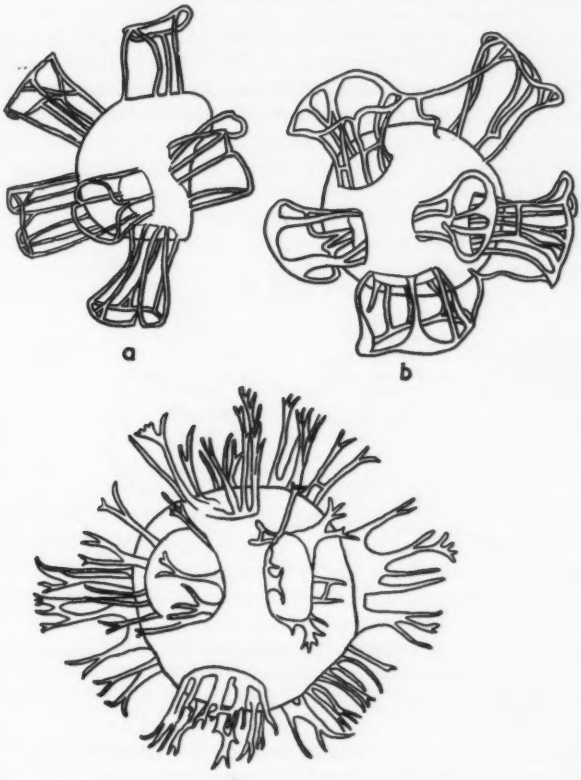
*Diagnosis.*—Shell spheroidal, bearing processes of varied character but always solid or with closed tips, whose points of origin are arranged in rings. The bases of adjacent processes may be coalescent: and adjacent processes may be linked by trabeculae at points along their length or at their tip, all processes of each ring sometimes being linked together by a single trabecula.

*Type Species.*—*Polystephanosphaera valensii* sp. nov. Other species attributed to this genus: *P. urnaformis* (Cookson, 1953), *P. calathus* (Sarjeant, 1960), both formerly attributed to the genus *Cannosphaeropsis*, and *P. paracalathus* sp. nov.

*Remarks.*—In the arrangement in circles of the processes, this new genus differs from all other genera of hystrichospheres so far erected.

*Cannosphaeropsis urnaformis* Cookson, 1953, is transferred to this new genus on the basis of its possessing groups of processes linked at their base and distally, rather than tubes with perforated walls. Deflandre and Cookson, 1955, mention both alternatives without expressing judgment on which is correct: their figures however suggest a strong similarity with the other species of *Polystephanosphaera*. Both this species and *P. paracalathus* sp. nov. occasionally show a partial linkage of process groups by trabeculae: however, the

association of trabeculae with process groups rather than in an overall "concentric system of trabeculae" (Deflandre, 1947) supports their removal from *Cannosphaeropsis* and their placing in this new genus.



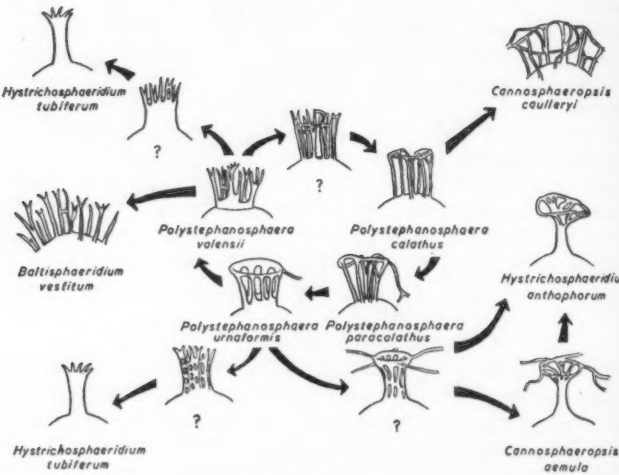

TEXT-FIG. 3.—Three species of *Polystephanosphaera* gen. nov.
a. *P. calathus* (Sarjeant, 1960) [Type specimen, SC 2/11/9].
b. *P. paracalathus* sp. nov. [Type specimen, WC 90/2/12].
c. The type species, *Polystephanosphaera valensii* sp. nov. [Type specimen, O 130/5/5]. All × 600.

Morphological series may be visualized by which this genus might arise from *Baltisphaeridium*, by the ordering of processes into groups: or from *Cannosphaeropsis*, by the ordering of processes into groups, the formation of trabeculae linking each group, and the reduction of

the system of trabeculae over the shell as a whole. Similarly, *Polystephanosphaera* might be visualized as giving rise to *Hystrichosphaeridium* by the filling in of the spaces between processes in each group, thus producing open-ended tubes (Text-fig. 4).

*Polystephanosphaera valensii* sp. nov.
Plate VI, figs. 5–7; Text-fig. 3c

*Diagnosis.*—A species of Polystephanosphaera having processes of very varied form, bifurcate or ramifying, slender or widened, sometimes




TEXT-FIG. 4.—Possible morphological transitions by which the processes of *Polystephanosphaera* spp. might be related to those of species of *Hystrichosphaeridium*, *Baltisphaeridium*, and *Cannosphaeropsis*. The process types marked "?" are postulated intermediates.

linked to adjacent processes in the same group either at the base or by trabeculae at some point along its length (but never at the outer extremity). 12 to 16 rings of processes present.

*Description.*—Shell spheroidal, yellowish in colour, its surface granular. There is some suggestion of a circular outline on the shell surface at the position of origin of each group of processes.

*Type Specimen.*—O 130/5/5 (Plate VI, fig. 5; Text-fig. 3c). *Dimensions.* Type: overall diameter 100 $\mu$. Diameter of shell 62 $\mu$, processes *c.* 20 $\mu$ long. Range observed: overall diameters 80 to 110 $\mu$.

*Remarks.*—Thirty-four specimens seen in an assemblage from the clay horizon below the upper leaf of the Upper White Oolite within

the Osmington Oolite series (*Perisphinctes plicatilis* Zone), 13 feet below the base of the *Trigonia clavellata* Beds in the cliffs at Osmington Mills, Dorset (grid reference 817736).

In the nature and arrangement of the processes, this species differs from all described species but resembles the forms described by Valensi (1956) under the name *Cannosphaeropsis* cf. *caulleryi*, from French Magdalenian flints of presumed Upper Jurassic age. Valensi describes the processes as arranged in semicircles; his figure indicates a high degree of similarity between his specimens and those from Dorset and, despite smaller dimensions and the more oval form of the shell, his specimens may well be attributable to this species.

The only other described species having processes comparable with those of *P. valensii* is *Baltisphaeridium vestitum* (Deflandre), also present at this horizon. Its processes are however scattered in random fashion over the shell surface and distinction was very readily made between the two species.

*Polystephanosphaera paracalathus* sp. nov.
Plate VI, fig. 4; Text-fig. 3b

*Diagnosis.*—A species of *Polystephanosphaera* having processes of variable thickness, sometimes bifurcating, sometimes simple, most often widening considerably at a constant distance from the shell surface. All processes of each group bend outwards from their point of origin and are connected together at their tips by a trabecula, each group of processes thus having the aspect of a skeletal vase with a bell mouth.

*Description.*—As in *P. calathus* (1960), the trabecula linking each group of processes at their tips appears to arise from the bifurcation of a single process in each group and the lateral extension of its branches to link up with the tips of other processes.

In some cases, adjacent groups of processes are connected by a single trabecula: these linking trabeculae have, hanging from them at about mid-point between process groups, a membraneous filament.

*Type Specimen.*—WC 90/2/12 (Plate VI, fig. 7; Text-fig. 3b). *Dimensions.* Type: overall diameter 92 $\mu$, diameter of shell 40 $\mu$, processes 26 $\mu$ in length. Range: overall diameter 85 to 100 $\mu$.

*Remarks.*—Eight specimens seen in an assemblage from the lowest exposed level of the Oxford Clay (*Kosmoceras jason* Zone) in Webb, Major and Company's Crook Hill brickyard, $\frac{1}{2}$ mile south of Chickerell Church, near Weymouth (grid reference 800646).

In the arrangement of processes and their linkage, this species differs from all the other described species and resembles *Polystephanosphaera calathus*, of the Oxford Clay of Yorkshire (1960). However, the more robust form of the processes and their broadening at the point of

linkage, and the bell-mouthed form of the process groups afford major differences from that species. The processes of *Polystephanosphaera urnaformis* (Cookson, 1953) differ in that they are coalescent at their base as well as at their tip.

## III. Acknowledgments

The contents of this paper form part of a series of investigations into the microplankton of the Upper Jurassic, carried out at the Geology Department, University of Sheffield, under tenure of Town Trustees Fellowship and a State supplemental award.

The author expresses his thanks to Professor L. R. Moore for the use of Departmental facilities; to Mr. G. S. Bryant for much technical assistance; and especially to Dr. Charles Downie for much valuable guidance and criticism.

## REFERENCES

Arkell, W. J., 1933. *The Jurassic System in Great Britain.* Oxford.

—— 1947. The Geology of the Country around Weymouth, Swanage, Corfe, and Lulworth. *Mem. Geol. Surv. Gt. Britain.*

Cookson, I. C., 1953. Records of the Occurrence of *Botryococcus braunii*, *Radiastrum*, and the Hystrichosphaeridae in Cainozoic deposits of Victoria. *Mem. Nat. Mus. Melbourne*, No. 18, 107–123.

Deflandre, G., 1947. Sur une nouvelle hystrichosphère des silex crétacés et sur les affinités du genre *Cannosphaeropsis*. *C.R. Acad. Sci. Paris*, 244, 1574–6.

—— and I. C. Cookson, 1955. Fossil Microplankton from Australian Late Mesozoic and Tertiary Sediments. *Austr. Jour. Mar. Freshw. Research*, vi, 242–313.

Downie, C., 1957. Microplankton from the Kimeridge Clay. *Quart. Journ. Geol. Soc.*, cxii, 413–434.

Eisenack, A., 1958. Mikroplankton aus dem norddeutschen Apt nebst einiger Bemerkungen über fossile Dinoflagellaten. *Neu. Jb. Geol. u. Pal.*, 106, 383–422.

Sarjeant, W. A. S., 1959. Microplankton from the Cornbrash of Yorkshire. *Geol. Mag.*, xcvi, 329–376.

—— 1960. Microplankton from the Kellaways Rock and Oxford Clay of Yorkshire. *Palaeontology* (in press).

Valensi, L., 1947. Note préliminaire à une étude des microfossiles de la region de Poitiers. *C.R. Acad. Sc. Paris*, 225, 816–8.

—— 1948. Sur quelques micro-organismes planctoniques des silex du Poitou et de Normandie. *Bull. Soc. Géol. Fr.*, xviii, 537–550.

—— 1953. Microfossiles des silex du Jurassique moyen. *Mem. Soc. Géol. Fr.*, No. 68, 1–100.

—— 1956. Étude micropaléontologique des silex du Magdalenien de Saint-Amand (Cher). *Bull. Soc. Préhist. Fr.*, lii, 584–596.

## EXPLANATION OF PLATE VI

Fig. 1.—*Baltisphaeridium lumectum* sp. nov. Holotype, O 128/15/22.
Fig. 2.—*Hystrichosphaeridium cribrotubiferum* sp. nov. Holotype, WF 108/13/3.
Fig. 3.—*Hystrichosphaeridium cribrotubiferum* sp. nov. (WF 108/3/3).
Fig. 4.—*Polystephanosphaera paracalathus* sp. nov. Holotype, WC 90/2/12.
Fig. 5.—*Polystephanosphaera valensii* gen. et. sp. nov. (O 130/11/4).
Fig. 6.—*Polystephanosphaera valensii* gen. et. sp. nov. Holotype, O 130/5/5.
Fig. 7.—*Polystephanosphaera valensii* gen. et. sp. nov. (O 130/20/1).
All × 400.

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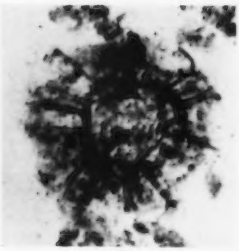
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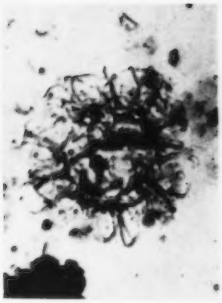
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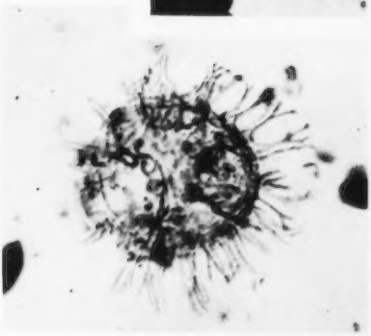
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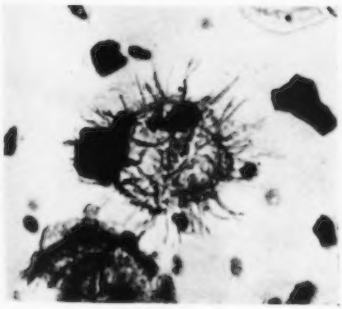
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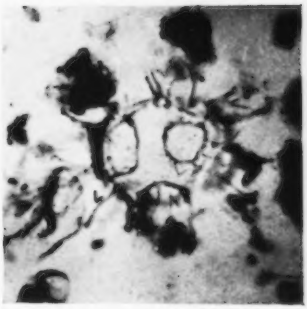
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HYSTRICHOSPHERES FROM THE UPPER JURASSIC.

*Facing p.* 144.

# A Garnet-Hornblende-Pyroxene Rock from Glenelg, Inverness-shire

By M. J. O'Hara

Abstract

A garnet-hornblende-two pyroxene rock from Glenelg is described. It is assigned to the eclogite facies by virtue of its density, mineral composition, and associations. Its chemical composition is that of a picrite-basalt. Comparison with other garnet-pyroxene assemblages suggests that there are no clear differences between the partition of major and minor elements in these minerals at the eclogite and granulite facies of metamorphism. A diagram to represent parageneses in basic and ultrabasic rocks of the eclogite facies is presented, and points of interest discussed.

The occurrence of genuine eclogites in the Lewisian inlier at Glenelg has been recognized by previous workers (Teall, 1891; Clough and others, 1910; Alderman, 1936).

Boulders of the rock to be described have been found on the slope north of Glen More, Glenelg, Inverness-shire, where they occur in a limited area on the eastern lip of the gorge of a stream which descends between the outcrops of the two limestone bands north of Balavoulin. The occurrence is about 400 feet above the road. The boulders are associated with a flinty pyritous type of eclogite, in which garnet is scarce, but occurs as relatively large patches (cf. Eskola, 1921, p. 49). No further boulders of the garnet-hornblende pyroxenite have been found on this hillside. The eclogite with which they are associated outcrops immediately below the locality in the sides of the gorge.

One boulder of similar material has been found on the slopes near Corrary, in Gleann Beag, among other rock types in the debris brought down by a stream.

The specimen G.8 which is described below, was collected from the locality in Glen More.

It is a compact, even grained, melanocratic rock of high specific gravity (3·57), which has an indistinct banding but no mineral orientation. The grain size is about 1 mm. The full mineralogy, with an approximate volume per cent mode is:—

*Primary.*—Clinopyroxene, 31 per cent; orthopyroxene, 25 per cent; garnet, 22 per cent; amphibole, 17 per cent; ores, 4 per cent; apatite, 1 per cent; zircon.

*Secondary.*—(*a*) Blue green amphibole replacing all the essential phases above (cf. Table 1, C and Table 2, II); (*b*) talc, cummingtonite, and anthophyllite pseudomorphing orthopyroxene, chlorite replacing garnet and orthopyroxene.

The primary minerals occur as rounded subhedral or anhedral grains, with the amphibole frequently interstitial or moulded on to the other minerals. Inclusions of the other minerals in garnet are common.

The clinopyroxene is bright green and lustrous in hand specimen, pale green and feebly pleochroic in thin section, with well-developed {110} cleavage. An X-ray single crystal study indicated that this is a homogeneous single monoclinic phase (Bown and Gay, unpublished data). The refractive indices are $\alpha = 1{\cdot}685$, $\beta = 1{\cdot}694$, $\gamma = 1{\cdot}711$; (+) $2V = 61°$; Sp.Gr., 3·35. The analysis (Table 1, II) indicates a composition $Wo_{46}$ $En_{41.5}$ $Fs_{12.5}$ neglecting the presence of sodium. The structural formula shows that the content of aluminium and sodium is small when compared with the examples discussed by Alderman (1936, p. 495), taken from undoubted eclogites, and the content of ferric iron is higher than in those examples. The majority of the trivalent elements are present in the Y group, where they pair with sodium to replace two divalent elements, about 13 per cent of the total molecule being so formed.

Orthopyroxene is pale brown in hand specimen, and faintly pleochroic in thin section, with the properties $\alpha = 1{\cdot}683$, brownish pink; $\beta = 1{\cdot}693$, pale yellow; $\gamma = 1{\cdot}700$, pale green; (−) $2V = 60°$; Sp.Gr., 3·47. X-ray examination indicated a homogeneous orthorhombic phase, but with the disorientation of the c-axis through about 8° in the plane (010), which has been noted before in orthopyroxenes from metamorphic rocks (Henry, 1942). The analysis (Table 1, V) presents no unusual features, and indicates a composition $Ca_{1.9}$ $Mg_{67.4}$ $Fe_{31.6}$.

The garnet is deep red in hand specimen, pale red and perfectly isotropic in thin section, with refractive index 1·778, cell side 11·552 Å, and Sp. Gr., 3·95. The analysis (Table 1, III) shows it to be a pyrope-almandine solid solution, with moderate amounts of grossular.

The amphibole is very dark green, and lustrous in hand specimen. It is strongly pleochroic in thin section, with $\alpha = 1{\cdot}652$, pale olive; $\beta = 1{\cdot}665$, olive; $\gamma = 1{\cdot}671$, deep green; and Sp. Gr., 3·17. An analysis is given in Table 1, IV.

The iron ores were examined in reflected light, the great majority of the material being optically similar to ilmenite, and apparently homogeneous at a magnification of 1,000. The anisotropy is strong, and the powder is more strongly magnetic than typical ilmenite. Powder photographs indicated the presence of substantial amounts of a spinel structure with the cell dimensions of magnetite. A partial analysis gave FeO 34·7 per cent; $Fe_2O_3$ 36·4 per cent; and $TiO_2$ 25·9 per cent. This may be calculated to a molecular composition $Ilmenite_{60}$ $Magnetite_{30}$ $Haematite_{10}$. There may be submicroscopic inclusions of magnetite in the ilmenite.

TABLE 1.

| | I | II | A | III | B | IV | C | V |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 44·9 | 52·47 | 53·48 | 38·46 | 40·3 | 44·56 | 42·17 | 53·05 |
| $TiO_2$ | 2·0 | 0·19 | 1·04 | 0·10 | tr | 1·20 | 1·00 | 0·19 |
| $Al_2O_3$ | 9·0 | 3·58 | 9·52 | 22·25 | 21·6 | 11·67 | 13·46 | 2·63 |
| $Fe_2O_3$ | 3·2 | 2·39 | 3·00 | 2·06 | 1·3 | 2·03 | 5·92 | 2·84 |
| FeO | 14·7 | 5·35 | 5·84 | 22·73 | 18·0 | 9·67 | 7·82 | 17·09 |
| MnO | 0·3 | 0·11 | n.d. | 0·97 | 0·7 | 0·09 | 0·15 | 0·19 |
| MgO | 14·2 | 13·44 | 6·34 | 8·42 | 11·2 | 14·68 | 14·46 | 23·76 |
| CaO | 9·7 | 20·66 | 14·87 | 5·06 | 7·2 | 10·82 | 11·76 | 0·49 |
| $Na_2O$ | 1·0 | 1·79 | 3·97 | | | 2·78 | 0·68 | 0·08 |
| $K_2O$ | 0·2 | 0·01 | 0·63 | | | 0·86 | 0·80 | 0·04 |
| $P_2O_5$ | 0·4 | 0·03 | n.d. | | | | | |
| $H_2O+$ | 0·4 | 0·21 | 0·73 | | | 1·65 | 1·53 | |
| $H_2O-$ | | 0·03 | nil | | | 0·06 | n.d. | |
| $Cr_2O_3$ | | 0·03 | | | | | | |
| Total | | 100·29 | 99·42 | 100·05 | 100·3 | 100·07 | 99·75 | 100·36 |
| Cations on basis of 24 oxygen atoms | | II | | III | | IV | | V |
| Si | | 7·74 | 8·0 | 5·90 | 5·9 | 6·52 | 8·0 | 7·74 | 8·0 |
| Al | | ·26 | | 4·01 | 4·0 | 1·48 | | ·26 | |
| | | ·36 | | | | ·53 | | ·19 | |
| $Fe^{3+}$ | | ·26 | | ·24 | | ·22 | | ·31 | |
| Ti | | ·02 | | ·01 | | ·13 | 5·3 | ·02 | |
| $Fe^{2+}$ | | ·66 | 8·0 | 2·91 | 6·0 | 1·18 | | 2·08 | 7·9 |
| Mn | | ·01 | | ·13 | | ·01 | | ·02 | |
| Mg | | 2·94 | | 1·92 | | 3·19 | | 5·16 | |
| Ca | | 3·27 | | ·83 | | 1·70 | | ·08 | |
| Na | | ·51 | | | | ·79 | 2·6 | | |
| K | | | | | | ·16 | | | |
| H | | | | | | 1·61 | 1·6 | | |
| Trace elements | | | | | | | | | |
| Cr | 1000 | 1250 | | 1000 | | 200 | | 1250 | |
| Ni | 600 | 300 | | 15 | | 1000 | | 800 | |
| Co | 60 | 35 | | 60 | | 100 | | 60 | |
| V | 220 | 450 | | 120 | | * | | 450 | |
| Ba | 15 | * | | * | | * | | 20 | |
| Li | 3 | 22 | | 2 | | * | | 2 | |
| Sr | 20 | 45 | | * | | * | | 45 | |
| Ga | 5 | 5 | | 5 | | 5 | | 10 | |
| Zr | 100 | 22 | | 45 | | 70 | | 22 | |
| Y | 15 | * | | 100 | | 10 | | * | |
| Sc | 15 | 45 | | 45 | | 30 | | * | |

I. Calculated composition and trace element content of specimen G.8.
II. Clinopyroxene of G.8.
A. Omphacite from eclogite, A.536 (Alderman, 1936).
III. Garnet of G.8.
B. Garnet from eclogite, east by north of Beinn a' Chapuill, Glenelg (Pollard, in Clough and others, 1910).
IV. Amphibole of G.8.
C. Amphibole from amphibolized eclogite, G.29 (Alderman, 1936).
V. Orthopyroxene of G.8.

TABLE 2.

*Analyses and Norms of Eclogites and Related Rocks.*

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| $SiO_2$ | 44·9 | 44·10 | 45·66 | 46·20 | 50·21 |
| $TiO_2$ | 2·0 | 2·07 | 1·13 | 0·95 | 1·69 |
| $Al_2O_3$ | 9·0 | 9·59 | 14·09 | 9·89 | 13·78 |
| $Fe_2O_3$ | 3·2 | 3·11 | 2·65 | 7·05 | 1·49 |
| FeO | 14·7 | 10·36 | 10·87 | 8·78 | 11·32 |
| MnO | 0·3 | — | 0·17 | 0·29 | 0·18 |
| MgO | 14·2 | 20·51 | 11·23 | 14·04 | 6·69 |
| CaO | 9·7 | 8·21 | 12·18 | 8·40 | 11·09 |
| $Na_2O$ | 1·0 | 1·52 | 1·24 | 1·01 | 2·12 |
| $K_2O$ | 0·2 | 0·62 | nil | 0·95 | 0·44 |
| $P_2O_5$ | 0·4 | 0·26 | n.d. | 0·07 | n.d. |
| $H_2O+$ | 0·4 | n.d. | 0·34 | 1·63 | 0·24 |
| $H_2O-$ | | — | 0·04 | 0·12 | 0·13 |
| $Cr_2O_3$ | 0·03 | | n.d. | nil | nil |
| $CO_2$ | | | | 0·14 | 0·05 |
| S &C. | | | | 0·13 | 0·13 |
| | 100·0 | 100·35 | 99·79 | 99·65 | 99·56 |
| Norms | | | | | |
| Qu | — | — | — | — | 1·14 |
| Or | 1·1 | 3·89 | — | 5·61 | 2·22 |
| Ab | 8·3 | 12·58 | 9·96 | 8·54 | 17·82 |
| An | 19·7 | 17·51 | 33·08 | 19·59 | 26·97 |
| Di | 21·1 | 16·80 | 21·23 | 17·61 | 23·23 |
| Hy | 22·7 | 0·63 | 14·48 | 29·65 | 21·82 |
| Ol | 17·2 | 39·85 | 14·19 | 4·54 | — |
| Mt | 4·7 | 4·41 | 3·94 | 10·22 | 2·09 |
| Il | 3·9 | 3·95 | 2·13 | 1·81 | 3·19 |
| Ap | 0·9 | 0·67 | — | — | — |
| Rest | 0·4 | | 0·50 | 2·07 | 0·30 |

I. Calculated composition of specimen G.8, garnet-hornblende-pyroxenite.
II. Picrite basalt, Réunion (Washington, 1917).
III. Amphibolized eclogite, Glenelg (Alderman, 1936).
IV. Eclogite nodule in Kimberlite (Williams, 1932).
V. Eclogite, A.536, Glenelg (Alderman, 1936).

Very subordinate amounts of bright yellow, strongly anisotropic pyrrhotite occur enclosed within, or moulded on to the ilmenite. Associated with this is much scarcer niccolite, which shows a weak anisotropy and colour variation from pale pink to pale yellow. Very rare grains of highly reflecting material with a pink tinged cream colour are seen with the niccolite. The surface of this material crumbled when scratched, and it may be native arsenic.

Anhedral grains of apatite, rather smaller than the general grain size are frequently associated with the ore mineral. Zircon is a scarce accessory, occurring as small, euhedral grains.

The composition of the rock has been calculated from the data

above, and is shown in Table 1, I. The trace elements in the rock and minerals were determined by Mr. R. Allen.

The rock composition is shown again in Table 2, I, together with its norm, and it is compared with the analyses and norms of a picrite basalt from Réunion; an amphibolized eclogite from Glenelg; an eclogite nodule in kimberlite; and an eclogite, A.536, from Glenelg. The nodule from kimberlite is not recorded as containing orthopyroxene, but it carries amphibole and mica as alteration products, and has a higher combined water content, and lower specific gravity than the garnet-hornblende pyroxenite from Glenelg, with which it is otherwise comparable.

It is evident that the rock described here is similar to a picrite basalt in composition, that similar rocks described as eclogites occur with true eclogites in the kimberlite pipes of South Africa, and that similar rocks described as amphibolized eclogite occur in the Glenelg district, where they are associated with true eclogites.

The high density, mineral paragenesis, and associations of this rock indicate that it has crystallized under the physical conditions of the eclogite facies, but with an amphibole as a primary member of the assemblage (cf. Fyfe, Turner, and Verhoogen, 1958, p. 235). There is no indication that this necessarily implies a transition towards amphibolite facies conditions (cf. von Knorring and Kennedy, 1958).

The orthopyroxene of this rock has a higher iron to magnesium ratio than the clinopyroxene, as is normal in igneous rocks, and in metamorphic rocks of the granulite and pyroxene hornfels facies (Muir and Tilley, 1958). The amphibole associated with these pyroxenes has a higher iron to magnesium ratio than either, which also appears to be normal in granulite facies assemblages, other than very magnesian ones (Buddington, 1952; Howie, 1955), but contrary to predictions from experimental data (Bowen and Schairer, 1935 (*a*)). The garnet has a higher iron to magnesium ratio than the rock or minerals other than iron ore, this being typical of iron-magnesium garnets in all investigated parageneses of the granulite and eclogite facies (see below).

Among the minor constituents titanium is enriched in amphibole relative to all other minerals except ilmenite, the content in the clinopyroxene being lower than in most igneous clinopyroxenes, but normal for metamorphic assemblages (Alderman, 1936; Howie, 1955; Muir and Tilley, 1958; Murray, 1954; Wilkinson, 1956, 1957; Brown, 1957). Manganese is concentrated in the garnet, and to a lesser extent in orthopyroxene relative to clinopyroxene. It is lowest in the amphibole, but nickel and cobalt show a reversed distribution. Strontium and vanadium are concentrated in the pyroxenes, and yttrium is

concentrated in the garnet (cf. Jaffe, 1951; Keith and Rustum Roy, 1954).

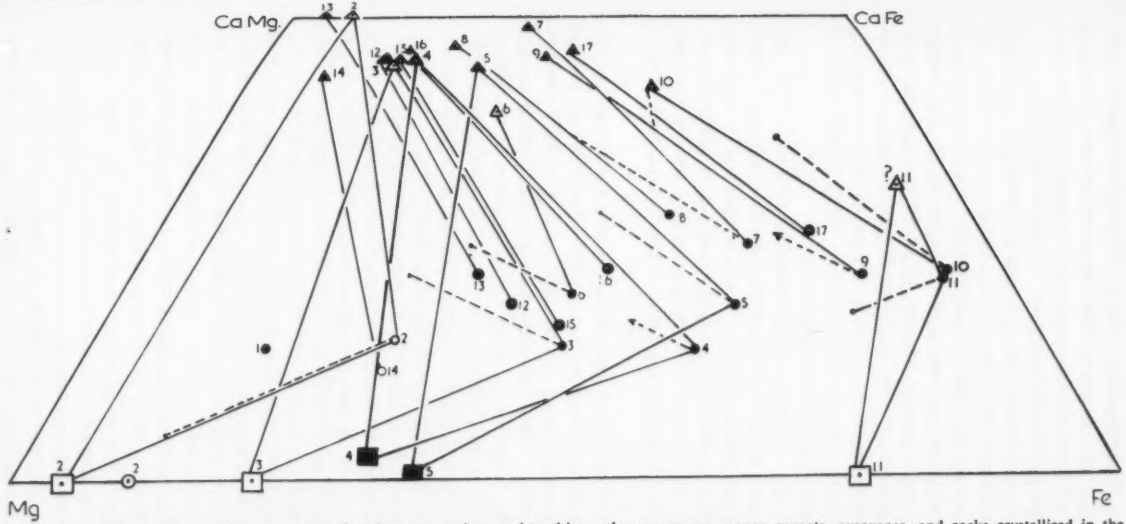
In these features, as in the partition of major elements, there are no clear differences between this rock and rocks of the granulite or amphibolite facies. The relationship between any pair of minerals is preserved independently of the presence or absence of other minerals in the assemblage. The exceptions to this generalization are the absence of a strong contrast between the content of strontium, vanadium, chromium, and titanium in clino- and orthopyroxene in the Glenelg rock, such a contrast being a feature of most granulite facies parageneses, and the varying calcium content of garnets, discussed below.

Garnet-pyroxene parageneses are encountered in the eclogite, pyroxene granulite, and hornblende granulite facies. Two publications have dealt with this subject recently (Buddington, 1952; Subramaniam, 1956). In the diagram, Text-fig. 1, points representing the compositions of minerals and rocks from garnet-pyroxene parageneses of the eclogite and granulite facies are shown. Assemblage (2) was determined from the specimen (A.2), in the Niggli collection, Cambridge, garnet having $n = 1{\cdot}745$; $a = 11{\cdot}530$ Å; Sp. Gr., 3·74. Orthopyroxene has $\beta = 1{\cdot}665$, $\gamma = 1{\cdot}671$; (+) $2V = 72°$. Clinopyroxene has $\alpha = 1{\cdot}675$, $\gamma = 1{\cdot}700$; (+) $2V = 58°$; and olivine has $\alpha = 1{\cdot}658$, $\gamma = 1{\cdot}692$; (+) $2V = 85°$. Eskola (1921) records a similar rock from Norway, his data suggesting a slightly more magnesian paragenesis, but with garnet still appreciably higher in iron relative to magnesia than the other minerals, and olivine again of higher iron to magnesia ratio than the associated orthopyroxene, as is expected in an equilibrium assemblage (Bowen and Schairer, 1935 (*b*); Ramberg and de Vore, 1951).

There is reason to doubt the compositions of metamorphic clinopyroxenes estimated from their optics (Muir and Tilley, 1958), particularly in the case of ferroaugite (11) Assemblage (6) probably does not represent equilibrium.

The tables and data published by Hess (1949), Winchell (1951), and Troger (1956) have been used in estimating mineral compositions.

The data considered in Text-fig. 1, and some other data not presented in that diagram (Howie, 1955; Howie and Subramaniam, 1957) confirm Buddington's (1952) observation that in the granulite facies garnet invariably has a higher iron to magnesium ratio than the rock and the pyroxenes. The diagram shows that this is also true of rocks from the eclogite facies, and Subramaniam (1956, p. 377) is wrong in stating, "In the case of eclogites a converse relationship was found; the FeO/MgO ratio of garnets being uniformly lower than those for the host rocks."




TEXT-FIG. 1.—Variation in atomic proportions of calcium, magnesium, and total iron plus manganese among garnets, pyroxenes, and rocks crystallized in the eclogite and granulite mineral facies. Solid ornament indicates analysed mineral, open ornament a composition obtained from optical and other data. Solid lines link co-existing minerals ; broken lines link rock compositions to their associated garnet. Triangles indicate clinopyroxene compositions, neglecting jadeite content ; small circles indicate garnet compositions ; squares indicate orthopyroxene, and a large circle indicates an olivine composition. Assemblages 1, 2, 4, 7, 8, 12–17 belong to the eclogite mineral facies, and 3, 5, 6, 9–11 to the granulite mineral facies.

(1) garnet, ultrabasic rock (Kokta and Nemec, 1936). (2) garnet-peridotite, Ticino, Switzerland, associated with eclogite and kyanite-eclogite (Grubenmann, 1908 ; Dal Vesco, 1953). (3) garnet-two pyroxenes-spinel-plagioclase-amphibole gneiss, Scourie, Sutherland (O'Hara, 1959). (4) garnet-hornblende-two pyroxenes rock, G.8, Glenelg. (5) garnet-augite-hypersthene-plagioclase gneiss, Scourie (O'Hara, 1959). (6) metagabbro, Adirondack Mts. (Buddington, 1952). (7) eclogite, A.536, Glenelg (Alderman, 1936 ; Tilley, personal communication). (8) eclogite (Angel and Schaider, 1950). (9) garnet-augite-plagioclase gneiss, Adirondack Mts. (10) garnet-two pyroxenes-plagioclase gneiss, Adirondack Mts. (11) garnet-ferroaugite-ferrohypersthene-plagioclase gneiss, Adirondack Mts. (Buddington, 1952). (12) eclogite, Liverpool Land, East Greenland (Sahlstein, 1935). (13) kyanite-eclogite, Weissenstein, Bavaria (Tilley, 1936). (14) eclogite, Almklovdalen, Norway (Eskola, 1921). (15) eclogite, Silden, Norway (Eskola, 1921). (16) eclogite, Burgstein, Tirol (quoted from Tilley, 1936). (17) eclogite, Vanelvsdalen, Norway (Eskola, 1921).

In his diagram (Subramaniam, 1956, p. 377), which is a similar plot to that used in Text-fig. 1, it is evident that every garnet, irrespective of facies, is of a higher iron to magnesium ratio than its host rock. This error has been repeated (Howie and Subramaniam, 1957).

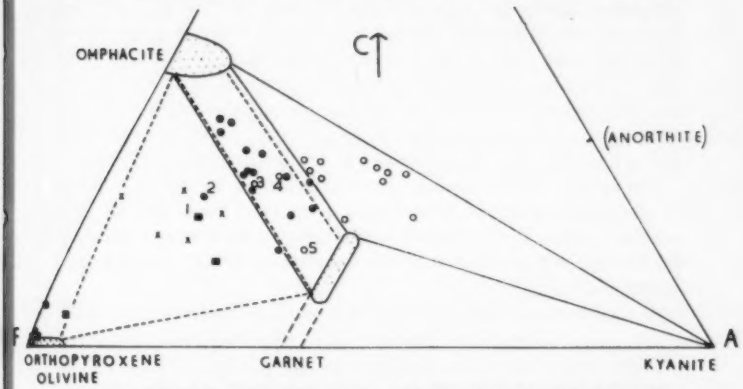
In that diagram Subramaniam attempts to distinguish a field of eclogite compositions from those of basic rocks of other facies. At least nine of the rocks within his " eclogite field " are probably not of eclogite facies, while all but one of the eclogites which plot outside the field appear to be genuine. It may be noted that both the rocks described as " eclogites " from Sittampundi contain primary plagioclase, and the specimen C.41, which is compared with a chemically very similar kyanite eclogite (Subramaniam, 1956, Table 32), is of lower density, and quite different mineralogy.

Subramaniam also attempts to distinguish a difference in tie line trend for rocks and garnets in the eclogite facies as opposed to other facies. This is not substantiated by the data, bearing in mind that some of the rocks quoted as " eclogite " are not of eclogite facies. The data shown in Text-fig. 1 above suggest that there is no facies significance to be attached to the trend of the rock-garnet tie line in this diagram.

The partition of calcium, magnesium, and iron between garnet and clinopyroxene appears to be the same in both granulite and eclogite facies rocks. No significance can be attached to the slight variation in the data plotted. The published data for the Glenelg eclogite (Alderman, 1936) suggested an anomalously low iron to magnesium ratio in the garnet. I am grateful to Professor Tilley for permission to incorporate the result of a new analysis of this garnet, which indicates that the assemblage conforms with the other data.

A feature of the diagram (Text-fig. 1), is the limited calcium content, irrespective of facies, of those garnet-clinopyroxene assemblages which also carry orthopyroxene, and the somewhat higher calcium content of garnets from orthopyroxene free assemblages. Reference to Text-fig. 2 suggests that the highest calcium contents in both garnet and clinopyroxene will be found in kyanite-bearing eclogites (cf. 13 of Text-fig. 1). The data suggest that there is no limit to the composition of almandine-pyrope-grossular garnets other than that produced by changes in the associated minerals. In the amphibolite facies garnet generally coexists with amphibole or biotite, and under such conditions the garnet is invariably much richer in iron relative to magnesia than either of the hydrous phases. This garnet is also poorer in its proportion of calcium than the amphibole. Except in very magnesian rocks, which are generally ultrabasic and hence do not contain garnet in the amphibolite facies, the presence of amphibole or biotite controls the composition of the garnet so that it is an almandine-rich type with relatively

small amounts of grossular in solid solution. In the granulite facies garnet coexists commonly with clinopyroxene, and usually with orthopyroxene as well. The presence of the latter mineral appears to limit the calcium content of the garnet, but in equilibrium with either pyroxene the calcium content of garnet appears to be higher than that associated with amphibole. The contrast in iron to magnesia ratio between coexisting pyroxene and garnet is less than that between amphibole and garnet, and hence the same rocks will contain more magnesian garnets in the granulite facies than in the amphibolite facies.




TEXT-FIG. 2.—Part of the ternary diagram A (= Al-Na-K); C (= Ca); F (= Mg + Mn + total iron), as atomic proportions, illustrating the paragenesis of kyanite-eclogites, eclogites, orthopyroxene eclogites, and garnet-bearing olivine rocks (after Tilley, 1936).

The extent of the composition fields of the minerals is based on analytical data, the sources of which are cited in the key to Text-fig. 1. Solid lines limit three principal fields of rock composition within which the rock can be expected to crystallize as (i) olivine or orthopyroxene-bearing eclogite, (ii) eclogite, or (iii) kyanite-eclogite. Broken tie-lines link the compositions of garnet and clinopyroxene from a kyanite-eclogite (Tilley, 1936), and garnet, clinopyroxene, and orthopyroxene from the specimen (G.8).

Points representing rock analyses from Switzerland (Dal Vesco, 1953), Norway (Eskola, 1921), Bavaria (Tilley, 1936), France (Briere, 1920), South Africa (Williams, 1932), and Glenelg (Alderman, 1936) are shown. Open circles represent kyanite-eclogites, filled circles represent eclogites, and filled squares represent orthopyroxene or olivine-bearing assemblages. Crosses represent the compositions of five rocks from South Africa not mentioned as containing orthopyroxene or olivine, but which contain an unspecified amount of amphibole and mica, possibly as alteration products. (1) represents the composition of (G.8). Other numbered points refer to rocks which fall outside the expected composition field :—(2) eclogite, Les Guerches, France. (3) kyanite-eclogite, Ticino, Switzerland. (4) and (5) kyanite-eclogites, South Africa.

Orthopyroxene free assemblages are usual in the eclogite facies, and in the absence of this mineral the calcium content of garnet coexisting with clinopyroxene increases to about 25 per cent of the X-group. The presence of clinopyroxene or amphibole in all common Fe-Mg garnet-bearing assemblages is probably the main factor in producing the observed restriction of calcium content in such garnets.

Very magnesian garnets are encountered in the eclogite facies, where

the assemblage garnet-olivine forms in the equivalents of picrites. In the granulite facies this assemblage is replaced by orthopyroxene-spinel apparently, and rocks which are both sufficiently magnesian and silica rich to carry a very magnesian garnet are rare.

An analysis of garnet from an eclogite east by north of Beinn a' Chapuill, Glenelg (Clough and others, 1910), suggests the presence of assemblages more magnesian than any yet described in detail from this district.

In the diagram (Text-fig. 2) are shown the probable mineral parageneses in the eclogite mineral facies for rocks of basic and ultrabasic igneous composition, ignoring the influence of water as a component. Silica deficient assemblages are rare in eclogites on account of the release of silica in the transformation of potential albite into jadeite, and the low silica content of garnet. Apart from olivine the only silica poor phases recorded from eclogite associations are corundum and spinel, which occur in nodules in kimberlite (Williams, 1932).

The eclogite facies appears to be characterized by the development of garnet-clinopyroxene assemblages in rocks of basic igneous composition, where the normative albite appears as jadeite molecule in the clinopyroxene. The mineral associations which are critical of eclogite facies are:—

(i) Garnet-clinopyroxene-quartz (but see Howie and Subramaniam, 1957); (ii) Clinopyroxene-kyanite; (iii) Garnet-olivine.

These assemblages are replaced in the granulite facies by the assemblages garnet-hypersthene-quartz, or hypersthene-clinopyroxene-quartz; by two pyroxenes and plagioclase, or by hypersthene-garnet-plagioclase; and by hypersthene-spinel, respectively. Certain rocks, rich in iron and magnesia, and poor in silica, crystallize as a clinopyroxene-pyrope/almandine garnet assemblage in the granulite facies. Where such rocks are poor in soda they may simulate eclogites, and the same rock crystallized under eclogite facies conditions might be very similar in appearance. Such rocks are high in normative anorthite, but their content of normative ferromagnesians is also high, and they do not fall in a field of compositions such that kyanite would be expected in the eclogite facies (cf. Tilley, 1936; Davidson, 1944). Garnet-clinopyroxene rocks with accessory hypersthene, plagioclase, and iron ore which appear to fall in this category occur in the Lewisian of South Harris (Davidson, 1944), and identical types are found in the Scourie district (Davidson, 1944; O'Hara, 1959). At Scourie these rocks are interbanded with basic gneisses, also of granulite facies, but which are chemically similar to the true eclogites from Glenelg, analysed by Alderman (1936). The garnet-pyroxene rocks at Scourie are associated with plagioclase-clinopyroxene-hypersthene assemblages in the basic rocks, and with the hypersthene-spinel assemblage in

ultrabasic rocks. The granulite facies as developed at Scourie cannot be equated with the eclogite facies, contrary to Davidson's (1944) conclusions, and the status of the " eclogites " of South Harris must be considered doubtful (cf. Fyfe, Turner, and Verhoogen, 1958, p. 235).

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## REFERENCES

Alderman, A. R., 1936. Eclogites from the neighbourhood of Glenelg, Inverness-shire. *Quart. Journ. Geol. Soc.*, xcii, 488–530.

Angel, F., and F. Schaider, 1950. Granat und omphazit aus dem eklogit des Gertrusk (Saualpe, Karnten). Carinthia II, *Naturweiss Beitr. Karntens. Jahrg.*, lviii–lx, 31–36.

Bowen, N. L., and J. Schairer, F. 1935 (*a*). Grunerite from Rockport, Massachusetts. *Amer. Min.*, xx, 543–551.

—— —— 1935 (*b*). The system FeO-MgO-$SiO_2$. *Amer. Journ. Sci.*, xxix, 151–217.

Briere, Y., 1920. Les Eclogites francaises. *Bull. Soc. Franc. Min.*, xliii, 72–222.

Brown, G. M., 1957. Pyroxenes from the early and middle stages of fractionation of the Skaergaard Intrusion, East Greenland. *Miner. Mag.*, xxxi, 511–543.

Buddington, A. F., 1952. The chemical petrology of some metamorphosed Adirondack gabbroic rocks. *Amer. Journ. Sci., Bowen Volume*, 37–84.

Clough, C. T., *et al.*, 1910. Geology of Glenelg, Lochalsh, and the south-east part of Skye. *Mem. Geol. Surv. Scotland.*

Dal Vesco, E., 1953. Genesi e metamorfosi delle rocce basiche e ultrabasiche nell'ambiente mesozonale dell'orogene Pennidico, Cantone Ticino. *Schweiz. Min. Petr. Mitt.*, xxxiii, 173–480.

Davidson, C. F., 1944. The archean rocks of the Rodil district, South Harris, Outer Hebrides. *Trans. Roy. Soc. Edinburgh*, lxi, 71–112.

Eskola, P., 1920. The Mineral Facies of Rocks. *Norsk. Geol. Tiddskr.*, vi, 143–194.

—— 1921. On the eclogites of Norway. *Vidensk. Skrift. I. Mat. Naturv. Klasse*, viii, 1–118.

Fyfe, W. S., F. J. Turner and J. Verhoogen, 1958. Metamorphic reactions and metamorphic facies. *Geol. Soc. Amer. Mem.*, lxxiii.

Grubenmann, U., 1908. Der granatolivinfels des Gordunotales, und seine begleitgesteine. *Viert. Nat. Ges. Zurich*, liii, 129–156.

Henry, N. F. M., 1942. Lamellar structure in orthopyroxenes. *Miner. Mag.*, xxvi, 179–189.

HESS, H. H., 1949. Chemical composition and optical properties of common clinopyroxenes. *Amer. Min.*, xxxvi, 621–666.

HOWIE, R. A., 1955. The Geochemistry of the charnockite series of Madras, India. *Trans. Roy. Soc. Edinburgh*, lxii, 725–768.

—— and SUBRAMANIAM, A. P., 1957. The paragenesis of garnet in charnockite, enderbite, and related granulites. *Miner. Mag.*, xxx, 565–587.

JAFFE, H. W., 1951. Role of Yttrium and other minor elements in the garnet group. *Amer. Min.*, xxxvi, 133–155.

KEITH, M. L., and RUSTUM ROY, 1954. Structural relations among double oxides of trivalent elements. *Amer. Min.*, xxxix, 1–23.

KENNEDY, W. Q., and O. VON KNORRING, 1958. The mineral paragenesis and metamorphic status of garnet-hornblende-pyroxene-scapolite gneiss from Ghana, Gold Coast. *Miner. Mag.*, xxxi, 846–859.

KOKTA, J., and K. NEMEC, 1936. Granat ultrabasickyck hornin od Cernina. *Veda. Prirodni. Praha*, xvii, 176–180.

MUIR, I. D., and C. E. TILLEY, 1958. The compositions of co-existing pyroxenes in metamorphic assemblages. *Geol. Mag.*, xcv, 403–409.

MURRAY, R. J., 1954. The clinopyroxenes of the Garbh Eilean sill, Shiant Isles. *Geol. Mag.*, xci, 17–31.

O'HARA, M. J., 1959. *Unpublished Ph.D. thesis*, Cambridge.

RAMBERG, H., and G. DE VORE, 1951. The distribution of Fe and Mg in co-existing olivines and pyroxenes. *Journ. Geol.*, lix, 193–210.

SAHLSTEIN, T. G., 1935. Petrographie der eklogitenschlusse in den gneissen des sud-westlichen Liverpool Landes in Ost Gronland. *Med. om Grønland*, xcv, 5.

SUBRAMANIAM, A. P., 1956. Mineralogy and petrology of the Sittampundi complex, Salem district, Madras state. *Bull. Geol. Soc. Amer.*, lxvii, 317–390.

TEALL, J. J. H., 1891. On an eclogite from Loch Duich. *Miner. Mag.*, ix, 217–218.

TILLEY, C. E., 1936. The paragenesis of kyanite eclogites. *Miner. Mag.*, xxiv, 422–432.

TROGER, W. E., 1956. *Optische bestimmung der minerale*. Stuttgart.

WASHINGTON, H. S., 1917. Chemical analyses of igneous rocks, 1884–1914. *U.S. Geol. Surv. Prof. Paper*, xcix.

WILKINSON, J. F. G., 1956. Clinopyroxenes of alkali olivine basalt magma. *Amer. Min.*, xli, 724–743.

—— 1957. The clinopyroxenes of a differentiated teschenite sill near Gunnedah, New South Wales. *Geol. Mag.*, xciv, 123–134.

WILLIAMS, A. F., 1932. *The genesis of diamond*. 2 vols. London.

WINCHELL, A. N., 1951. *Elements of optical mineralogy*. Part II. New York.

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# Nomenclatural Problems in the Mesozoic Rhynchonelloidea

By D. V. Ager

Abstract

Eight nomenclatural problems connected with Mesozoic brachiopods of the suborder Rhynchonelloidea are discussed and solutions suggested. A new genus is proposed related to *Halorella* and a new name is given to a species of *Norella*.

In connection with work on the Mesozoic rhynchonelloids for the "Treatise on Invertebrate Paleontology", several minor taxonomic problems have been encountered which it is desirable to clear up at this stage. The author would like to record his thanks to Dr. H. M. Muir-Wood, Mr. R. V. Melville, and Mr. C. W. Wright for information and discussion on certain points. Miss M. Pugh kindly helped with bibliographic matters.

## 1. *Acanthothiris* or *Acanthothyris*?

This well-known spinose Jurassic rhynchonellid is variously recorded in the literature under the above two spellings of the name. The second version is certainly the more popular, but is not the original usage.

The genus *Acanthothiris* [*sic*] was erected by d'Orbigny in 1850. The alternative spelling was introduced by Bronn (1862) as what would now be called a "*nomen correctum*". Since then it has been used by many authors, notably Hall and Clarke (1894, p. 836). Under the present reading of the International Rules of Zoological Nomenclature there appears to be no justification for such a change and the original spelling should therefore be retained.

## 2. The valid name for *Austriella* Bittner

This is the most confused nomenclatural problem which has arisen over the generic names of Mesozoic rhynchonelloids. Bittner first used the name *Austriella* (1890, pp. 314–5) for a large group of Upper Triassic Alpine rhynchonellids typified by *Rhynchonella dilatata* Suess. *Austriella* was, however, already preoccupied by Tenison-Woods (1883, p. 82) for a lamellibranch. Various workers in the 1920s noted and corrected this error independently. Patte proposed the name *Jacobella* in 1926 to replace *Austriella*, but his substitute name had in fact already been used by Jeannet in 1908 (it was to be used again by Passendorfer in 1930 and by Mercier in 1935). Strand (1928) proposed *Austriellula* for *Austriella* and the following year Schuchert and LeVene (1929) proposed *Austriellina* for the same purpose.

*Austriellula* Strand (1928) is therefore the valid name for this form, with *Austriella* Bittner (1890) and *Jacobella* Patte (1926) as rejected junior homonyms and *Austriellina* Schuchert and LeVene (1929) as a rejected junior synonym.

### 3. The type species of *Halorella* Bittner

This genus was first named by Bittner (1884, p. 107) for "der Gruppe der *Rh. pedata* oder *amphitoma*", and he clearly regarded these two species as equal types of his new genus. *Halorella* was first actually named in a footnote, but the first combination (on the same page) was in "*Rhynchonella amphitoma* (*Halorella*) *curvifrons* Qu". Bittner repeated the implication of joint types in his classic monograph of the brachiopods of the Alpine Trias (1890). In this he referred to *Halorella* (p. 172) as "der Gruppe der *Rh. amphitoma* oder *pedata*" and he mentioned *amphitoma* first in the text, though *pedata* comes first in his systematic descriptions. Here it becomes obvious that his use of the two names arose from his uncertainty as to whether or not they are distinct, although he treats them quite separately in his descriptions.

Hall and Clarke (1894, p. 832) named *H. amphitoma* (Bronn) as the type species of *Halorella* (and repeated one of Bittner's figures of this species). This was a valid selection of lectotype and there would seem to be no further doubt in the matter. Termier and Termier, however (1949 and other papers), maintained that the "genotype" was *Rhynchonella pedata* Bronn which "correspond pro-parte á *Terebratula amphitoma* Bronn . . ."

*H. amphitoma* (Bronn) and *H. pedata* (Bronn) are probably synonymous, so the problem is purely legalistic, but the former must be regarded as the type species of *Halorella*.

### 4. A new genus related to *Halorella*

In his great monograph of Alpine Triassic brachiopods, Bittner (1890) included in his genus *Halorella* a large variety of markedly contrasting forms. The type species, *H. amphitoma*, is strongly costate, but there is also a very distinctive series of smooth forms which clearly deserve generic separation. Besides the absence of costae, they also differ from *Halorella* s. s. in the development of the anterior commissure and in the form of the dorsal median septum. This is ample justification for a new genus among the brachiopods, and it is quite probable that the long-needed revision of the Alpine Triassic Brachiopoda will reveal many more, even within this group. The Trias was a time of great nomenclatural depression, but certainly not of morphological uniformity. Many more such genera are needed in the Trias before we can hope to disentangle the threads of Mesozoic

brachiopod evolution. At the same time it should be pointed out that the new genus is obviously related to *Halorella*, having the same general form and beak characters, and showing the same tendency towards asymmetry and the development of opposite sulci in the two valves.

The following name is therefore proposed:

HALORELLOIDEA gen. nov.

Type species: *Halorella rectifrons* Bittner, 1890, pp. 187–188, pl. XXI, figs. 31–52; pl. XXII, figs. 1–36. Also included in this genus are the following species: *H. ancilla* (Mojsisovics) (= *Halorella ancilla* Suess Ms.), *H. plicatifrons* (Bittner), and *H. curvifrons* (Quenstedt).

Bittner himself separated these forms (op. cit. p. 185) as " Formen vom Typus der *Halorella ancilla* Suess spec."

*H. rectifrons* is preferred as the type species since *H. ancilla*, as figured by Bittner, shows a considerable range of ornament, from costate to almost completely smooth, and clearly requires further study. *H. curvifrons* is exactly like the others except for the quite exceptional development of a strong uniplication in the anterior commissure.

### 5. The type species of *Norella* Bittner

Bittner proposed the name *Norella* (1890, p. 315) for a group of smooth, sulcate rhynchonellids from the Alpine Trias. In his list of species, he named " *Rhynchonella sellaris* Laube " first as the oldest, but he did not figure it as he did the others. Hall and Clarke (1894, p. 833) named *N. sellaris* as type species, but repeated Bittner's figure of his own species *N. refractifrons*, which was the first to be described.

Bittner gave his synonymy of *R. sellaris* as follows (op. cit. p. 85):

" ?*Rhynchonella sellaris* Laube spec.
syn. *Spirigera sellaris Klipst.* spec. bei Laube . . .
non *Terebratula sellaris* Klipst . . ! "

*Terebratula sellaris* Klipstein, 1845 (which was later transferred to the genus *Rhynchonella* by d'Orbigny), is a small *Homoeorhynchia*-type brachiopod from the Trias of St. Cassian, with a strong, sharp dorsal fold. It obviously has no connection with the genus *Norella* as intended by Bittner and as generally interpreted since. It is most undesirable that " *T.*" *sellaris* Klipstein should be regarded as the type species of *Norella* and the author has recently submitted an application to the International Commission on Zoological Nomenclature for the plenary powers to be used to designate *Rhynchonella refractifrons* Bittner as the type species instead (Ager, 1960).

Nevertheless a new name is still required for " *Norella sellaris* " as interpreted by Laube and Bittner. The latter clearly had no doubt that

this was not the same as " *T.*" *sellaris* Klipstein and the present author is of the same opinion. The following name is therefore proposed:

*Norella bittneri* sp. nov.

1866 *Spirigera sellaris* Laube, p. 254, pl. XII fig. 8.
1890 ?*Rhynchonella sellaris* Laube, Bittner, p. 85.
1894 *Norella sellaris* Laube, Hall and Clarke, p. 833.

The name is given as a tribute to the great Austrian palaeontologist.

### 6. The type species of *Rhynchonella* Fischer

It has been pointed out to the present author by Mr. C. W. Wright that he was incorrect in preferring *loxia* to *loxiae* as the spelling of the type species of this well-known genus (Ager, 1957, p. 10). The spelling *loxia* was first introduced by Hall and Clarke (1894, p. 822) and has since been used by most authors. Fischer's binomen was " *Rhynchonella Loxiae* ". The capital " L " and the termination " -ae " indicate that the specific name was a genitive singular of a first declension noun treated as a proper name. It was suggested by the present author (loc. cit.) that the name referred to the Crossbill (*Loxia*), and it seems very probable that Fischer intended his binomen " *Rhynchonella Loxiae* " [*sic*] to refer to the " little beak of the crossbill ", though the resemblance is not obvious. There are no grounds for treating the specific name as adjectival and consequently emending it to *loxia.* The correct binomen is therefore *Rhynchonella loxiae.*

### 7. The names *Rhynchonellopsis* and *Terebratulopsis*

The problems connected with the use of the name *Rhynchonellopsis* have already been dealt with by Cooper and Muir-Wood (1951), but this is a useful opportunity to draw attention to the multiple use of this name, and to explain the situation in a little more detail.

The name *Rhynchonellopsis* has been used for three different brachiopods. Vincent (1893, p. 50) proposed it as a subgenus of *Terebratulina* for a Tertiary form from Belgium. This usage has priority. Böse (1894) used the same name for an Upper Jurassic form which is probably an indeterminate juvenile. Muir-Wood and Cooper (op. cit.) renamed this form *Capillirostra.* Much later Di Gregorio (1930) subdivided *Rhynchonellina* into two subgenera according to whether they were smooth or costate. The costate forms were called *Rhynchonellopsis*, and for this usage of the name Muir-Wood and Cooper (op. cit.) substituted *Sulcirostra.* The smooth ones were called *Terebratulopsis*, but since the type species *R. suessi* Gemmellaro comes into this category, *Terebratulopsis* is regarded as a synonym of *Rhynchonellina.* In his original description Gregorio (op. cit.) used the name *Terebratulopsis* " per le conchiglie lisce come la *bilobata* ", but this does not constitute a type designation. The present author

therefore here selects *R. suessi* (which was included in the sub-genus by Gregorio) as the type species of *Terebratulopsis*. The latter then automatically becomes an objective junior synonym of *Rhynchonellina* and can be rejected.

### 8. The so-called genus *Bicornes* Quenstedt

This name is sometimes included in lists of Mesozoic rhynchonellid genera. It was, for example, so included by Roger in his excellent section on the Brachiopoda in Piveteau's " Traité de Paléontologie " (1952, p. 95). However, it is obvious in the original text that Quenstedt (1852) applied the name to rhynchonellids in general and had no intention of using it in a generic sense. It was comparable in its original usage to the name *Cincta* in the same work. This was given respectability by Buckman (1907) with an excessive number of species, and is now well established as a genus of Lower Jurassic zeilleriids, but no one has used *Bicornes* in a similar way. Unfortunately Schuchert and LeVene (1929, p. 34) resurrected the name and quoted *Terebratula livonica* von Buch as type; this was the first name mentioned under " Terebratulae bicornes " by Quenstedt. However, though Schuchert and LeVene (like other authors) list *Bicornes* as a Jurassic genus, there is no doubt that " *T.*" *livonica* is a Palaeozoic form. It was figured by Quenstedt (op. cit. pl. 35, fig. 42) from the Grauwacke of Daun, Eifel. Therefore, though the name is probably best forgotten, it would seem to apply to a Palaeozoic form and has no place in the Mesozoic nomenclature.

## REFERENCES


Ager, D. V., 1957. The true *Rhynchonella*. *Palaeontology*, i, 1–15.

—— 1960. Proposed use of the plenary powers to designate *Rhynchonella refractifrons* Bittner, 1890, as the type-species of the nominal genus *Norella* Bittner, 1890 (Phylum Brachiopoda, Class Articulata). *Bull. Zool. Nomencl.* (in the press).

Bittner, A., 1884. Aus den Salzburger Kalkhochgebirgen — Zur Stellung der Hallstätter Kalke. *Verh. k.k. geol. Reichs.*, vi, 99–113.

—— 1890. Brachiopoden der alpinen Trias. *ibid.*, xiv, 1–325.

Böse, E., 1894. Monographie des Genus *Rhynchonellina* Gemm. *Palaeontographica*, xli, 49–80.

Bronn, H. G., 1862. *Die Klassen und Ordnungen der Weichthiere* (*Malacozoa*) *in Wort und Bild*, 3 (1). Leipzig.

Buckman, S. S., 1907. Some species of the genus *Cincta*. *Proc. Cotteswold Nat. Field Club*, xvi, 41–63.

Cooper, G. A., and H. M. Muir-Wood, 1951. Brachiopod homonyms. *J. Washington Acad. Sci.*, xli, 6, 195–196.

Gregorio, A. di., 1930. Monografia dei fossili liassici di Monte San Giuliano. *Ann. Géol. Paléont.*, livr. 53, 1–56.

Hall, J., and J. M. Clarke, 1894. An introduction to the study of the Brachiopoda. *N.Y. State Geol. Surv.*, 13th Ann. Rep. (for 1893), 2, 751–943.

Klipstein, A. von, 1845. *Beiträge zur geologischen und topographischen Kenntniss der östlichen Alpen.*, 2 (1), Giessen.

LAUBE, G. C., 1866. Die Fauna der Schichten von St.-Cassian. Ein Beitrag zur Paläontologie der alpinen Trias. *Denkschr. k. Akad. Wiss. Wien*, xxv, (2), 1–76.

ORBIGNY, A. D', 1850. *Prodrome de paléontologie stratigraphique universelle.* 1 (1849), Paris.

PATTE, E., 1926. Études paléontologiques relatives a la géologie de l'Est du Tonkin (Paléozoique et Trias). *Bull. Serv. géol. Indochine*, xv (1), 1–204.

QUENSTEDT, F. A., 1852. *Handbuch der Petrefaktenkunde.* (1st ed.) part 2, Tübingen.

ROGER, J., 1952. Classe des Brachiopodes *in* Piveteau, J. *Traité de Paléontologie*, 2, Paris.

SCHUCHERT, C., and C. M. LEVENE, 1929. *Brachiopoda. Fossilium Catalogus.* 1. *Animalia.* part 42, Berlin.

STRAND, E., 1928. Miscellanea nomenclatorica zoologica et palaeontologica. I–II. *Arch. Naturgesch. Berlin*, 92 A, 37–38.

TENISON-WOODS, J. E., 1883. On some new marine *Mollusca. Trans. Roy. Soc. Victoria*, xvii (1881), 80–83.

TERMIER, H., and G. TERMIER, 1949. Sur les genres *Halorella* et *Dzieduszyckia. Notes Mém. Serv. Min. Carte géol. Maroc*, lxxiv, 113–115.

VINCENT, É., 1893. Contribution a la paléontologie des terrains tertiares de la Belgique. Brachiopodes. *Ann. Soc. malac. Belgique*, xxviii, 38–64.

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# The Ordovician Rocks of the Chatwall District, Shropshire

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Abstract

A detailed account is given of the stratigraphical succession of the Chatwall Flags and Sandstone of the type area in South Shropshire, and a restricted use of the name " Chatwall Sandstone " is proposed.

## I. Introduction

The stratigraphical term Chatwall Sandstone was introduced by Callaway (1877, pp. 654–6) for the subdivision of the Caradoc Series overlying the Harnage Shales in south Shropshire east of the Church Stretton Hills. No details were given regarding thickness, but the horizon was said to form a ridge parallel to that of the Hoar Edge Grits (the basal subdivision of the local Caradoc Series) and to contain " *Orthis alternata* Sow.". Later La Touche (1884, p. 12) listed the Chatwall Sandstone as if it were synonymous with the Horderley Sandstone, and Lapworth (1887, p. 79), in reviewing the succession of the Caradoc Series east of The Longmynd, used the name for the strata between the Harnage Shales and what he called the Longville (originally Cheney Longville) Flags. In a subsequent account, Lapworth and Watts (1894, pp. 319–320) employed Chatwall Sandstone in the same sense and the fauna was said to include abundant *Orthis alternata*, with *Homalonotus bisulcatus*, *Strophomena grandis*, *Glyptocrinus basalis*, and *Leptaena sericea*. The name *Alternata* Limestone was introduced by Cobbold (1900, pp. 10, 48, 50, 52) who described it as marking a boundary between the Soudley Sandstone and the Longville Flags. Lapworth and Watts (1910, p. 755) referred to the " Chatwall or Soudley Sandstones ", which they regarded as Murchison's typical " Caradoc Sandstones ", and noted the importance of the *Alternata* Limestone, which was said to occur near the base of the succeeding Cheney Longville Flags. Further new stratigraphical terms were added subsequently by Lapworth (1916) when he divided the Ordovician rocks of Shropshire into " Groups " on the basis of place names in the county. The relevant portion of his succession is:

| | |
|---|---|
| Chatwall Group . . | *Alternata* Limestone<br>Upper Chatwall Sandstone<br>Lower Chatwall Sandstone<br>(*Glyptocrinus* Flags) |
| Harnage Group . . | Harnage Shales |

No details were published by Lapworth, either in his original paper or subsequently, but his terminology was applied by the Geological Survey to the northern Caradoc District covered by the Shrewsbury Memoir (Pocock *et al.*, 1938, pp. 81 *et seq.*) and its usage has been discussed by the writer in a more recent review (Dean, 1958,

p. 213). The succession employed by the Geological Survey was as follows:

| | |
|---|---|
| Chatwall Group . . | *Alternata* Limestone, 20–30 feet<br>Chatwall Sandstone, 100–120 feet<br>Chatwall Flags, 200–220 feet |
| Harnage Group . . | Harnage Shales, 1,000–1,100 feet |

In detailed pioneer work on the shelly Caradoc faunas of south Shropshire, on the basis of which several faunally defined Stages were introduced, Bancroft (1929, p. 40) showed that a faunal break exists at Soudley Quarry, 4¼ miles south-south-west of Chatwall, where the *Alternata* Limestone (Upper Longvillian Substage) rests on rocks belonging to the upper half of the Soudleyan Stage, the Soudley Sandstone. More recently it has been suggested that the Upper Chatwall Sandstone of Lapworth is an arenaceous facies of the lowest part of the *Alternata* Limestone and is of Upper Longvillian age (Dean, 1958, pp. 208, 216). In view of the fact that virtually no information was available regarding the detailed faunal succession in the Chatwall District, 4¼ miles north-east of Church Stretton, it was decided to map the area on the 25-inch scale and make a bed-by-bed collection from the critical part of the sequence. All the specimens collected are housed in the British Museum (Natural History). In addition, specimens in the Geological Survey and Museum have been re-examined and I am indebted to Mr. J. D. D. Smith for facilitating this work. Professor W. F. Whittard has kindly read and criticized this manuscript.

## II. General Succession

The rocks will be first discussed in the order in which they are encountered along the line A–B (Text-fig. 1).

Stratigraphically the lowest strata found in the immediate vicinity of Chatwall belong to what have been termed the Harnage Shales. At the type-locality of Coundmoor, near Cressage, part of the Harnage Shales is cut out by faulting and only the lowest portion of their succession elsewhere is found there (Dean, 1958, p. 215). In terms of the succession of shelly faunas established for South Shropshire they represent only the basal zone of *Reuscholithus reuschi* of the Harnagian Stage. The higher beds are well exposed in the roadside north-west of Chatwall Farm, and also in the cartway leading south-south-west from Chatwall Lawn to the road where they comprise, in addition to shales, dark, grey-green, often micaceous, blocky mudstones. These do not resemble the typical Harnage Shales lithologically and are more suggestive of part of the Glenburrell Beds as developed in the valley of the River Onny near Horderley, strata which belong to the highest part of the Harnagian Stage and the lower part of the Soudleyan Stage.

The Harnage Shales, using the name in a broad sense, of the Chatwall District are followed in the succession by a series of dark, grey-green, flaggy sandstones and occasional mudstones, usually termed the Chatwall, or sometimes *Glyptocrinus*, Flags on account of the abun-

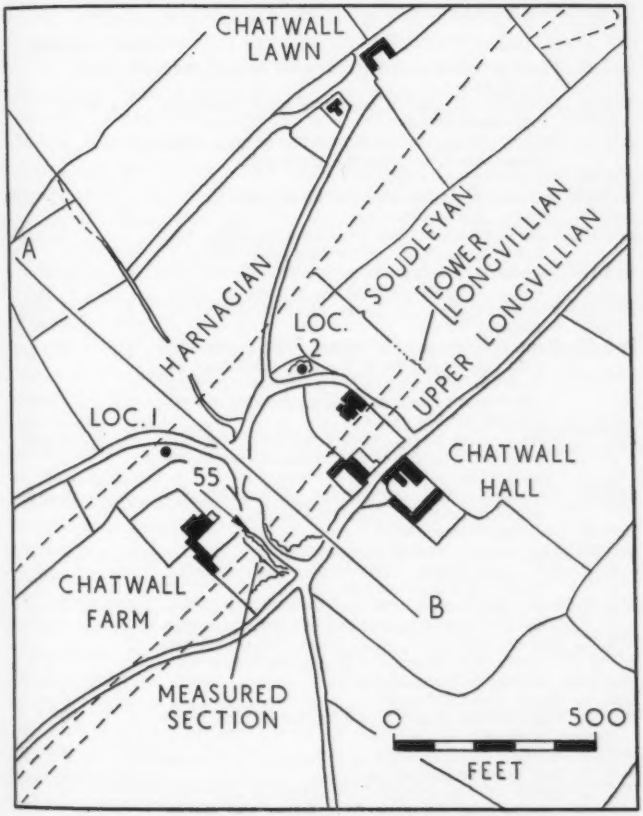


FIG. 1.—Sketch-map of the Chatwall district, Shropshire.

dance of the remains of *Rhaphanocrinus* [*Glyptocrinus*] *basalis* (M'Coy). The sandstones are exposed in the roadside north-west of Chatwall Farm (Loc. 1, Text-fig. 1) and in the quarry about 450 feet north-east of Chatwall Farm (Loc. 2). About 180 feet of strata separate the base of the sandstone series and the top of the rocks exposed at Loc. 2.

There follows a small gap in the succession of about 40 feet, and the next strata examined occur in, and near, the disused quarry immediately south-east of Chatwall Farm. The lowest subdivision (Bed 1) of the following measured section was examined through the narrow cutting running south-eastwards from the above quarry almost to the cross-roads 250 feet south-east of Chatwall Farm.

| | | *Feet.* | *Inches.* |
|---|---|---|---|
| Bed 23. | Flaggy, yellow sandstones with several thin fossil bands. | 5 to 6 | |
| Bed 22. | Conspicuous band of weathered sandy limestone with many fossils. | up to 11 | |
| Bed 21. | Yellow flaggy sandstones with several thin, impersistent, weathered fossil bands. | 5 | 0 |
| Bed 20. | Massive yellow sandstone . . . . . | 2 | 6 |
| Bed 19. | Weathered fossiliferous limestone band . . | | 7½ to 10 |
| Bed 18. | Massive yellow sandstone . . . . . | 2 | 2 |
| Bed 17. | Weathered calcareous horizon containing two fossiliferous bands of variable thickness. | | 6½ to 8 |
| Bed 16. | Massive and flaggy, yellow sandstones, with an 8-inch band of sandy shales at base. | 4 | 10 |
| Bed 15. | Yellow flaggy sandstones and jointed sandy shales. | 5 | 3 *circa* |
| Bed 14. | Weathered, calcareous, yellow, flaggy sandstones with occasional fossil bands. Thickness includes 3- to 7-inch band of fossiliferous, coarse, calcareous sandstone at base, just above well-defined bedding-plane. | 4 | 8 |
| Bed 13. | Massive and flaggy, current-bedded, buff and grey-green sandstones with occasional bands of pebbles. | 4 | 3 *circa* |
| Bed 12. | Well-developed conglomerate band with occasional intercalated sandstone bands. | | 6 to 8 |
| Bed 11. | Buff flaggy sandstones . . . . . | 2 | 3 |
| Bed 10. | Impersistent band of conglomerate . . . | | 1 to 7 |
| Bed 9. | Buff sandstones, the lower half massive, becoming flaggy towards the top. | 3 | 5 *circa* |
| Bed 8. | Buff sandy shales and flaggy sandstones, conspicuously well jointed and weathering maroon. | 2 | 5 |
| Bed 7. | Buff or light-brown sandstones with occasional bands of pebbles, extending upwards to a well-defined bedding-plane. | 2 | |
| Bed 6. | Band of conglomerate . . . . . | | 5 |
| Bed 5. | Light-brown, massive, and current-bedded sandstones. | 1 | 10 |
| Bed 4. | Band of conglomerate . . . . . | | 4 *circa* |
| Bed 3. | Buff massive sandstones . . . . . | 1 | 8 |
| Bed 2. | Series of thick bands of conglomerate with occasional horizons of massive and flaggy sandstone. | 6 | 8 |
| Bed 1. | Buff, current-bedded, flaggy sandstones with about 35 ft. exposed shale and occasional pebbles. | | |

The topmost strata of this measured sequence (Bed 23) pass upwards in an additional few feet of yellow-brown, weathered, calcareous sandstones and occasional limestone bands which have been quarried on either side of the south-eastern end of the cutting.

## III. Faunal Succession

No shelly fossils have yet been discovered in the so-called Harnage Shales of the Chatwall District and it is not possible to place them with confidence in the sequence of shelly Zones and Stages. A few graptolites found by the Officers of the Geological Survey (Pocock *et al.*, 1938, p. 250) included *Climacograptus minimus* (Carruthers), *Orthograptus calcaratus* (Lapworth) var. *vulgatus* Elles and Wood, and *O. truncatus* (Lapworth). The earliest faunas to be found in the succeeding flaggy sandstones were collected from and near Loc. 1 (Text-fig. 1) and are housed in the Geological Survey and Museum. They include *Broeggerolithus* cf. *broeggeri* (Bancroft), *Brongniartella* cf. *parva* Harper, calymenid indet., ?*Parabasilicus powisi* (Murchison), *Camarotoechia* sp., *Rafinesquina expansa* (J. de C. Sowerby), *Rafinesquina* sp., *Soudleyella* sp., *Sowerbyella* sp., *Rhaphanocrinus basalis* (M'Coy), and a few graptolites.

The rocks at Loc. 2 are about 150 feet higher in the succession than those of Loc. 1. They have yielded an abundant shelly fauna which comprises *Broeggerolithus* cf. *broeggeri*, *Brongniartella* cf. *parva*, *Proetidella* cf. *fearnsidesi* Bancroft, cf. *Parabasilicus powisi* (Murchison), ?*Reacalymene pusulosa* Shirley, *Camarotoechia* sp., *Kjaerina* aff. *jonesi* Bancroft, *Rafinesquina expansa*, *Soudleyella* cf. *avelinei* (Bancroft), *Sowerbyella soudleyensis* Jones, *Cyclonema* sp., and *Rhaphanocrinus basalis*. Both faunas are obviously of Soudleyan age and the presence of trinucleids close to *Broeggerolithus broeggeri* (Bancroft) strongly suggests that the *B. broeggeri* Zone is present, as similar forms have been found only at that horizon in the Onny Valley (Dean, 1960, p. 112).

Between the rocks of Loc. 2 and the next seen there is a gap of about 40 feet in the succession exposed, and the next fossiliferous horizons are in the lowest 5 feet and topmost 4 feet of Bed 1 in the measured section already listed. There the fauna is sparse and poorly preserved, comprising only *Kjaerina* aff. *jonesi* Bancroft, together with occasional *Sinuites* sp. indet. The type-specimens of *Kjaerina jonesi* were described by Bancroft from the Lower Longvillian Substage of the Onny Valley, but similar forms appear earlier in Shropshire and it is doubtful whether the species is of value in detailed correlations. In view of the relatively small distance of Bed 1 above the probably Lower Soudleyan beds of Loc. 2 it is considered unlikely that Bed 1 represents an horizon later than the Upper Soudleyan.

The group of strata consisting of Beds 2 to 13 is, on the whole, poorly fossiliferous. The lower beds include a series of thick bands of conglomerate, the lowest of which (Bed 2) is sometimes seem to truncate some of the current-bedded sandstones of Bed 1, and it is believed that a stratigraphical break separates Beds 1 and 2. The earliest fossils found include *Lophospira* cf. *gyrogonia* (M'Coy) in Bed 8, and

*Dalmanella* cf. *lepta* (Bancroft) together with an indeterminate *Broeggerolithus* in Bed 9. The next succeeding faunas were collected from two horizons in Bed 13. The first of these, 1 ft. 10 in. above the base, yielded an indeterminate asaphid trilobite, *Brongniartella*? sp., and *Dalmanella* cf. *lepta* (Bancroft), whilst the second, and more fossiliferous, accounting for the topmost 8 inches of Bed 13, was found to contain *Dalmanella lepta*, *Rostricellula* sp., *Sowerbyella soudleyensis* Jones, *Broeggerolithus* cf. *globiceps* (Bancroft), *Brongniartella* cf. *parva* Harper, ? *Parabasilicus powisi* (Murchison), and *Lophospira* sp. ind.

In the Onny Valley the upper half of the Soudleyan Stage is succeeded by the lowest part of the Lower Longvillian Substage, which embraces the zones of (i) *Dalmanella horderleyensis*, (ii) *Dalmanella indica* and *D. lepta*, and (iii) *Bancroftina typa*. No evidence of *D. horderleyensis* or *B. typa* and their associated faunas has been found in the Chatwall section and the zones are presumed to be absent from the district. The Lower Longvillian is, in fact, represented by only an undetermined portion of the Zone of *D. indica* and *D. lepta*. As developed in Bed 13 the latter horizon is separated by a faunal break from Bed 14 which contains an abundant and characteristic fauna of Upper Longvillian age, including *Bancroftina* cf. *robusta* (Bancroft), *Kjaerina bipartita* (Salter), *Sowerbyella sericea* (J. de C. Sowerby), *S. soudleyensis* Jones, *Broeggerolithus* cf. *longiceps* (Bancroft), and *Brongniartella bisulcata* (M'Coy). The sudden faunal change between Beds 13 and 14 is accompanied by an equally marked change in lithology, from a buff, massive, poorly fossiliferous sandstone to a highly fossiliferous, yellow-brown, friable, calcareous sandstone and shales. It is not proposed to list the faunas found in the remaining beds of the section, from Bed 15 upwards. Fossil bands are numerous and each of them may be expected to yield some or all of the following: *Bancroftina robusta* (Bancroft), *Dolerorthis duftonensis* (Reed), *Heterorthis alternata*, *Kjaerina bipartita*, *Sowerbyella sericea*, *S. soudleyensis*, *Strophomena grandis* (J. de C. Sowerby), *Cyrtolites nodosus* (Salter), *Sinuites soudleyensis* Reed, *Lophospira* cf. *gyrogonia* (M'Coy), *Ambonychia obliqua* (J. de C. Sowerby), *Broeggerolithus longiceps*, *Brongniartella bisulcata*, and *Phacopidina apiculata* (M'Coy). This assemblage is characteristic of the *Alternata* Limestone, of Upper Longvillian age, throughout the Caradoc Area of south Shropshire.

It has already been noted that the term Harnage Shales may only be used in a broad sense for the Chatwall district, because the rocks probably include part of the Glenburrell Beds of the Onny Valley. The name " Chatwall or *Glyptocrinus* Flags " can be applied without much difficulty for the sandstones immediately overlying the so-called " Harnage Shales ", but higher strata such as those of Bed 1 in the

measured section contain conspicuously fewer crinoid ossicles and are also lighter in colour. Nevertheless the term should be used to include all the arenaceous beds above the " Harnage Shales " (*s.l.*) and below the base of Bed 2 in the measured section.

The name Chatwall Sandstone appears to have been used to cover all the beds in the cutting south-east of Chatwall Farm, whilst *Alternata* Limestone has been reserved for the strata higher in the succession than Bed 23. However, most of the fossiliferous horizons within the sequence of Beds 14 to 23 are basically nothing more than deeply-weathered limestone lenses such as are typical of the *Alternata* Limestone, wherever it crops out, and the subdivision should therefore embrace all those strata of Upper Longvillian age. We are thus left with an intermediate group of beds (2 to 13) comprising some 26 feet of sandstones and conglomerates which represent only the middle portion of the Lower Longvillian Substage, and it is suggested that the name " Chatwall Sandstone " be restricted to these deposits, whilst the terms Lower and Upper Chatwall Sandstone be abandoned. The Chatwall succession may then be summarized as follows:

| | |
|---|---|
| Upper Longvillian . . | *Alternata* Limestone. Bed 14 and above. |
| | *Unconformity* (*Bancroftina typa* Zone absent) |
| Lower Longvillian . . | Chatwall Sandstone (*s.s.*) + *Dalmanella lepta*. Beds 2–13 inclusive. |
| | *Unconformity* (*Dalmanella horderleyensis* Zone absent) |
| Soudleyan . . . | Chatwall or *Glyptocrinus* Flags, including all arenaceous strata up to and including Bed 1. |
| ?Harnagian . . . | Harnage Shales (*s.l.*), probably including at the top the equivalent of the lowest Glenburrell Beds of the Onny Valley. |

The accompanying correlation table (Text-fig. 2) illustrates something of the difficulties encountered in south Shropshire should correlation of locally-named sandstones within the Caradoc Series be attempted on lithological grounds alone. Diachronism exists in the basal deposits, of Costonian and Harnagian age (Dean, 1958), and the faunas of the lowest Chatwall Flags at Chatwall (Loc. 2) indicate that the shallowing conditions which produced the Lower Horderley Sandstone of the Onny Valley during the Upper Soudleyan came into being earlier, during Lower Soudleyan times, in the northern part of the Caradoc Area. Although the succession in the middle Caradoc Series of the Onny Valley is apparently continuous, it has been known for some time that farther north at Soudley, 2 miles south-east of Church Stretton, the whole of the Lower Longvillian is missing and the *Alternata* Limestone rests on the Soudley Sandstone of Upper Soudleyan age. The re-examination of the succession at Chatwall shows that the stratigraphical break was prolonged there sporadically throughout most of the Lower Longvillian, leading to the formation

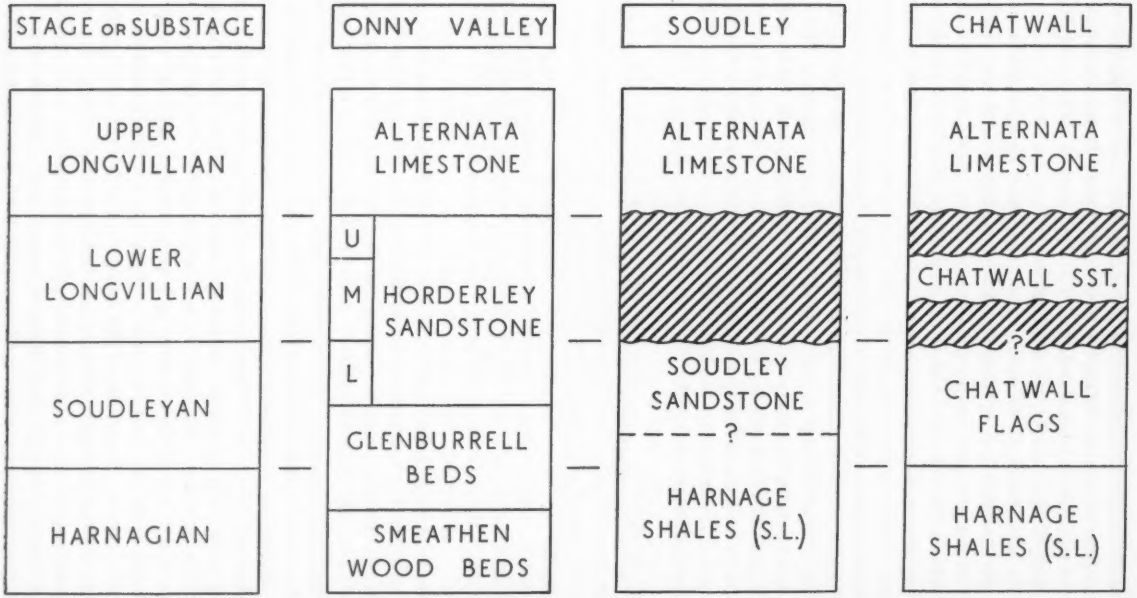


FIG. 2.—Table showing the stratigraphical position of the Chatwall Sandstone (s.s.).

locally of two unconformities, separated by the Chatwall Sandstone as now restricted. The latter, as the result of either erosion or non-deposition, is not found at Soudley.

## REFERENCES

BANCROFT, B. B., 1929. Some new genera and species of Strophomenacea from the Upper Ordovician of Shropshire. *Manchester Lit. Phil. Soc. Mem.*, lxxiii, 33–65.

CALLAWAY, C., 1877. On a new area of Upper Cambrian rocks in south Shropshire, with a description of a new fauna. *Quart. Journ. Geol. Soc.*, xxxiii, 652–671.

COBBOLD, E. S., 1900. Geology. In *Church Stretton*, 1, Shrewsbury.

DEAN, W. T., 1958. The faunal succession in the Caradoc Series of south Shropshire. *Bull. Brit. Mus.* (*Nat. Hist.*) *Geol.*, iii, 191–231.

—— 1960. The Ordovician trilobite faunas of south Shropshire. 1. *Ibid.* iv, 71–143.

LAPWORTH, C., 1887. Preliminary note on the Ordovician rocks of Shropshire. *Geol. Mag.*, xxiv, 78–80.

—— 1916. In "Palaeontological Work". *Summ. Progr. Geol. Surv. Gt. Britain*, 1915, 36–8.

—— and W. W. WATTS, 1894. The geology of south Shropshire. *Proc. Geol. Assoc.*, xiii, 297–355.

—— and —— 1910. "Shropshire" *in* "Geology in the Field", 739–769. London.

LA TOUCHE, J. D., 1884. *A handbook of the geology of Shropshire.* London and Shrewsbury.

POCOCK, R. W., T. H. WHITEHEAD, C. B. WEDD, and T. ROBERTSON, 1938. Shrewsbury District, including the Hanwood Coalfield (Sheet 152 New Series). *Mem. Geol. Surv. Gt. Britain.*

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# CORRESPONDENCE

## THE SOUTHERN UPLAND FAULT IN IRELAND

SIR,—Dr. McKerrow's (1959) recent discussion of the Salrock Fault in relation to the Southern Upland Fault is in agreement with my (1951) earlier discussion inasmuch as I had pointed out important differences between the two fault systems. However, I had earlier also suggested that the Salrock Fault is of considerable local importance, dividing the Ordovician rocks into two facies, an allochthonous north of the fault and an autochthonous south of the fault. I had further suggested that the Salrock Fault may continue eastward south of Lough Nafooey separating the Mweelrea grit on the north from other Ordovician beds on the south. Now, Dr. McKerrow stated (1959, p. 351) "The Salrock Fault does not continue due east of Lough Nafooey. Lower Palaeozoic rocks crop out for six miles between the lough and the Lower Carboniferous overstep and they show no sign of any major fault continuing eastwards along the line suggested by Bailey and Holtedahl". Although Dr. McKerrow later admitted that a certain fault mapped northeast of Lough Nafooey might be a continuation of the Salrock Fault, the fault concerned does not agree with the line I suggested which is an east–west line south of Lough Nafooey.

Dr. McKerrow most kindly loaned me the typescript of his joint paper with Dr. Campbell presented before the Geological Society of London on 12th November, 1958. In that paper, the authors stated that the Glenummera slate thins towards the east and disappears near Bunnacunneen. They state that the presence of fragments of slate in the base of the overlying Mweelrea grit indicates that the Glenummera slate suffered erosion before the deposition of the Mweelrea grit. They further state that faulting is partly responsible for the disappearance of the Glenummera slate to the east. We are all in agreement that considerably smaller thickness of Mweelrea grit occurs in the southern than in the northern limb of the large syncline which occupies the Formnamore Plateau and which was named the Maumtrasna syncline by McKerrow and Campbell. They considered that this southward thinning is an expression of original sedimentation conditions. While I do not wish to dispute this, I had earlier suggested (1951, p. 46) that the eastward continuation of the Salrock Fault system is responsible for the eastward disappearance of the Glenummera slate. In any event, while accepting McKerrow and Campbell's interpretation involving conditions of sedimentation, I would like to point out that both the Glenummera slate and the Leenane grits are present on the south flank of Rinavore. Both are absent east of the right-handed NW–SE fault between Rinavore and Bunnacunneen, and I consider it most unlikely that both formations could have thinned out within the short distance involved. The Salrock Fault is apparently the only agency that could possibly be invoked in explanation of the disappearance of these two formations. If this is so, then the Salrock Fault must have a very much greater throw at this point than that suggested by Dr. McKerrow.

Dr. McKerrow appears to have done rather more detailed field work south of Lough Nafooey than I have. I would therefore like to ask him to state whatever field evidence he has that throws light on this, our apparent disagreement.

### BIBLIOGRAPHY


McKERROW, W. S., 1959. The Southern Upland Fault in Ireland. *Geol. Mag.*, xcvi, 347–352.

—— and CAMPBELL, C. J., 1959. The Lower Palaeozoic rocks of North-West Galway. *Geol. Soc. Lond. Proc.*, 19–25.

THEOKRITOFF, G., 1951. Ordovician Rocks near Leenane, Ireland. *Proc. Roy. Irish Acad.*, liv, 25–49.



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*12th January, 1960.*

SIR,—I am glad that Mr. Theokritoff agrees with me that there are important differences between the Salrock Fault and the Southern Upland Fault, though in his paper (1951, p. 47) he merely states that the former "is an overthrust from the north; it is thus not comparable with the Southern Upland Fault". There are more important distinctions than this (McKerrow, 1959).

The Salrock Fault is clearly post-Silurian, and I fail to see why Mr. Theokritoff should point out with such emphasis (both in his 1951 paper and in his letter) that he thinks it separates different Lower Ordovician facies. If he had closely investigated the area around Bunnacunneen, he would have found that all the west of Ireland Lower Ordovician facies are present to the east and south of the Salrock Fault. With Dr. C. J. Campbell (1960), I have found that the (probably Llanvirn) Glenummera Slate outcrops on the western and north-eastern slopes of this hill (i.e. to the east of the dextral NW–SE fault between Rinavore and Bunnacunneen mentioned in the above letter). It follows that the grits below the slate are Lower Ordovician. These grits continue, with only slight breaks due to faulting, to the north of the spilites at Curraghrevagh, so that the area immediately south of Lough Nafooey is entirely Lower Ordovician. Mr. Theokritoff is thus wrong in following the conclusions of Gardiner and Reynolds (1914), who, because they also did not map Bunnacunneen, thought that the grits present south of the lough were the Upper Ordovician Mweelrea Grits.

North-east of Bunnacunneen, the Salrock Fault separates the Lower and Upper Ordovician grits; its throw is unknown. This need not be great, as the Glenummera Slate is seen to thin out and disappear; the presence of slate fragments in the base of the overlying Mweelrea Grits shows that this disappearance is at least partly due to erosion. The thinning of the Lower Ordovician grits does not affect any conclusions as to the throw—they occur on both sides of the fault.

The continuation of the Salrock Fault may be traced along the ridge to the north-west of Curraghrevagh Stream before being lost below the alluvium south-west of Lough Nafooey. There is no evidence that the fault suddenly swings to the east to pass south of the Lough. It is last seen, at Curraghrevagh, trending north-east, and it would seem reasonable to expect any continuation to lie in that direction.

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*22nd January, 1960.*

## REFERENCES

GARDINER, C. I., and S. H. REYNOLDS, 1914. The Ordovician and Silurian rocks of the Lough Nafooey area (County Galway). *Quart. Journ. Geol. Soc.*, lxx, 104–118.

MCKERROW, W. S., 1959. The Southern Upland Fault in Ireland. *Geol. Mag.*, xcvi, 347–352.

—— and C. J. CAMPBELL, 1960. The stratigraphy and structure of the Lower Palaeozoic rocks of north-west Galway. *Sci. Proc. R. Dublin Soc.* (in the press).

THEOKRITOFF, G., 1951. Ordovician rocks near Leenane, Ireland. *Proc. Roy. Irish Acad.*, liv, 25–49.

## CENOMANIAN AMMONITE ZONES

SIR,—There is a curious anomaly in the present scheme of subdivision of the Cenomanian into ammonite zones, viz:—

| | |
|---|---|
| Upper Cenomanian . | . { *Utaturiceras vicinale*<br>*Acanthoceras rhotomagense* |
| Lower Cenomanian . | . { *Mantelliceras mantelli*<br>*Mantelliceras martimpreyi* |

Since 1926, when Spath introduced the Indian "*Acanthoceras*" *vicinale* (Stoliczka) as an index-fossil for the topmost beds of the British Cenomanian,

a *vicinale* Zone has been quoted as part of the standard Cretaceous succession; it has been written into the world's text-books and has taken its place alongside the classic ammonite zones of the European Mesozoic.

Study of British material and the literature has failed to satisfy me that a single specimen of the *vicinale* group has ever been found in the Upper Cenomanian, in Europe or elsewhere. On the contrary, where the *vicinale* Zone appears to be most firmly established, i.e. in Madagascar, a check of original published records shows that what little evidence of horizon there is indicates a *low* Cenomanian level for the *vicinale* group.

The idea that " *A.*" *vicinale* occupies a position near the boundary of the Cenomanian and the Turonian seems to have originated with Kossmat (1895, p. 200; 1897, pp. 25, 131), who inferred its horizon from the matrix. Kossmat was also struck by the resemblance of the ammonite to the Lower Turonian " *Ac.*" *swallovi* (Shumard)—i.e. *Metoicoceras*.

*Ammonites vicinalis* is also important as the type species of the genus *Utaturiceras* Wright, which is regarded as the earliest member of the Metoicoceratinae and a link between the Acanthoceratinae and the Turonian *Metoicoceras* (Wright, 1956; 1957, p. L 416). Compared with *Metoicoceras*, the special features of *Utaturiceras* are said to be a row of siphonal tubercles which may weaken on the outer whorl and a more complex suture.

Stoliczka (1864, p. 84, p. xliv) gave a very full description of *A. vicinalis* and devoted a whole folio plate to illustrations of the ammonite in different stages of growth. Neither in this account nor that of later authors is there mention or depiction of siphonal tubercles at any size. In some of Stoliczka's figures (6*a*, 8*a*) the whorl-profile is gently convex between the ventro-lateral tubercles, a feature commonly seen in *Mantelliceras*.

In whorl-shape, coiling, sculpture, and suture-line *A. vicinalis* can be matched with basal Cenomanian *Mantelliceras* of the type of *M. saxbii* (Sharpe), which Spath (1926, p. 424) styled " a closely allied British equivalent " of *M. martimpreyi*. So close is the agreement between some Chloritic Marl specimens from southern England and Stoliczka's figures that specific separation is difficult. Stoliczka himself thought that *A. vicinalis* and *A. saxbii* might be synonyms.

The relationship of *A. vicinalis* with these early, compressed forms of *Mantelliceras* was seen by Pervinquière (1907, p. 288); if we wish to separate them from the inflated *mantelli* type, with an extra lateral tubercle, the name *Submantelliceras* Spath, 1923, may be used in a subgeneric sense.

Ammonites resembling immature *A. vicinalis* in side view, though with a reduced suture and a row of siphonal tubercles in the young, are found in the topmost Cenomanian (Jukes-Browne's Bed C) of Devon (e.g. Geological Survey Museum No. 98364). They appear to be congeneric with those described by Stephenson (1955, pl. 5, figs. 1–10) from the Upper Cenomanian of Texas as *Tarrantoceras rotatile*. Other forms which occur in the same bed and which have been mistakenly included in " *Utaturiceras* " belong to an undescribed group allied to *Protacanthoceras* and *Dunveganoceras* (e.g. British Museum, Natural History, Nos. C 56619–20). Whereas *Mantelliceras* (" *Utaturiceras* ") of the *vicinale-saxbii* group have sutures with the backward-slanting series of auxiliaries found in the ancestral *Stoliczkaia*, these Devon forms have more linear suture-lines, with very small second lateral lobe and plumper elements. It is uncertain that they are connected directly with either *Mantelliceras* or *Metoicoceras*.

These observations indicate that *M. vicinale* cannot be used as a guide fossil for the topmost zone of the Cenomanian, and that in fact any zone based on *vicinale* is the same as the *martimpreyi* Zone at the base of the Stage. It may be suggested that " *Utaturiceras* " is a fallacious concept combining characters of *M. vicinale* and other, unrelated, acanthoceratid ammonites; as defined by its type species it is a subjective synonym of *Mantelliceras* Hyatt, 1903, and *Submantelliceras* Spath, 1923. Some change in zonal nomenclature is required to accommodate the topmost beds of the British Cenomanian, characterized by species of *Protacanthoceras*, *Euomphaloceras*, *Calycoceras*, and *Eucalycoceras*.

Fuller details of this research and pictures of the relevant ammonites will be published in due course. The essential information is contained in the following bibliographical references.

## REFERENCES

BESAIRIE, H., and M. COLLIGNON. 1956. Le système crétacé à Madagascar. *Haut. Comm. Madagascar, Trav. Bur. géol.* no. 77.

KOSSMAT, F. 1895–98. Unterschungen über die Südindische Kreideformation. *Beitr. Paläont. Geol. Öster.-Ungarns u. des Orients*, Bd. 9, 11, 12.

PERVINQUIÈRE, L. 1907. Étude de paléontologie tunisienne. 1. Céphalopodes des terrains secondaires. *Carte Géol. Tunisie.*

SPATH, L. F. 1926. On the zones of the Cenomanian and the uppermost Albian. *Proc. Geol. Assoc.*, 37, 420–32.

STEPHENSON, L. W. 1955. Basal Eagle Ford fauna (Cenomanian) in Johnson and Tarrant Counties, Texas. *U.S. Geol. Surv. Prof. Paper* 274-C.

STOLICZKA, F. 1861–66. The fossil Cephalopoda of the Cretaceous rocks of Southern India. Ammonoidea, etc. *Palaeont. Indica*, I.

WRIGHT, C. W. 1956. Notes on the Cretaceous ammonites. III. *Utaturiceras* gen. nov. and the Metoicoceratinae. *Ann. Mag. Nat. Hist.* (12), 9, 391–3.

—— 1957. *In:* R. C. Moore (ed.), *Treatise on invertebrate paleontology.* Pt. L, Mollusca 4, Cephalopoda: Ammonoidea. Univ. Kansas Press.

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R. CASEY.

*14th January*, 1960.

## DEVONIAN–CARBONIFEROUS BOUNDARY

SIR,—I wonder why the explanation of the relations between the Carboniferous and Devonian rocks of S.W. England and S.W. Ireland did not occur to workers on these problems many years ago.

Anyone looking at the fossils in the Barnstaple Museum must recognize at once that the Pilton Beds are in part of Upper Devonian Age. Also, it is obvious, as Vaughan claimed, that some part of the Pilton Beds may extend into the lower part of the Carboniferous, possibly into the *Zaphrentis* zone. Thus the Pilton Beds form an apparently continuous passage between the Upper Devonian and the lower part of the Carboniferous.

In the Pembroke and Tenby Memoir, E. E. L. Dixon showed that such a passage occurred in S.W. Pembrokeshire and it was impossible to suggest where a boundary could be drawn between the two formations. These results confirm the remarkably acute observations of Salter who showed that in Pembrokeshire the Upper Old Red Sandstone developed into a marine facies which could be closely compared with the Pilton, Baggy, and Marwood Beds of North Devon.

A little earlier than the Pembroke and Tenby Memoir, another Geological Survey Memoir—Haverfordwest—had appeared. In that memoir the gradual encroachment of the base of the Millstone Grit on the Carboniferous Limestone (Viséan) development was described until in the neighbourhood of Haverfordwest, *Reticuloceras*-bearing shales rested unconformably on $S_1$ of the Viséan and a few miles further west the Millstone Grit had overstepped the whole of the Viséan.

You have only to combine these two relationships as developed in S.W. Pembrokeshire to arrive at the solution of the so-called Carboniferous Shale problem which was raised by Jukes in Ireland. In S.W. Ireland fossiliferous marine Upper Devonian in a slaty development apparently passes up conformably into Coal Measure slates without the intervention of the Carboniferous Limestone so typically developed further east around Cork.

73 BARTON ROAD, CAMBRIDGE.

O. T. JONES.

*8th February, 1960.*

# REVIEWS

INTRODUCTION TO HISTORICAL GEOLOGY. By R. C. MOORE (2nd edition). pp. ix + 656. McGraw Hill Publishing Co., 1958. Price 62*s*.

This edition has the same aim as its predecessor: to present an essentially readable account of stratigraphical geology for North American students, avoiding so far as possible the use of fossil and formational names. It has been greatly enlarged by increasing not merely the number of pages but their size, which unfortunately calls for the use of double-column type. In particular, the chapter on the Pre-Cambrian, here called the Cryptozoic Eon, has been entirely rewritten and more than doubled in content. A large number of figures have been added to what was already lavishly illustrated by European standards, and a section on economic resources now follows the account of each geological system. The small palaeogeographical maps of the old edition are replaced by double-page maps of a smaller part of the North American continent showing the outcrop and probable sub-surface distribution of each system (and also the location of universities and colleges offering instruction in Historical Geology). Correlation tables are larger in scope and further elaborated by diagrammatic representation of lithological succession, the gain in factual information being somewhat offset by loss of clarity. The palaeontological appendix has been greatly extended both in text and illustration, but even here generic names have been largely avoided. A glossary of geological terms supplements the index and the inner cover papers are utilized for a table showing stratigraphical distribution of principal groups of animals and plants, and a simplified three-colour geological map of Europe. Those who found the first edition a valuable text should find the second still more so.

O. M. B. B.

THE PLEISTOCENE OF CEYLON. By P. E. P. DERANIYAGALA. pp. viii + 164, with 40 figs. and 58 pls. Ceylon National Museums Publication, Government Press, Ceylon, 1958. Price Rs 8·50.

The greater part of the book is virtually a monograph of the Quaternary vertebrates of Ceylon. This is preceded by 42 pages dealing with other evidence for the Quaternary history of the island, including not only stratigraphy and geomorphology, but also such subjects as the composition of the present fauna and flora.

In these introductory pages the presentation of the material may seem scrappy and inconclusive, but so, it appears, is the evidence itself, even by normal Pleistocene standards. The field, moreover, is one in which very few have worked besides Mr. Deraniyagala. Meanwhile, although the significance of much of this information is still obscure, future workers will be grateful to find it gathered into one volume. They should be warned, incidentally, that correlation-trouble is likely to be severe; there are few river-terraces in Ceylon, and many signs of recent earth-movements.

It is the latter part of the book that is of special interest, for most of the fossils described belong to the Ratnapura fauna, discovered by Mr. Deraniyagala in the 1930s. It occurs in fluviatile sands and gravels in the south-west of the island and comprises about twenty species of vertebrates, including the probably neanderthaloid *Homo sinhaleyus*. Some of the species are of very recent origin, but others are characteristic of the Upper Siwaliks of northern India and are therefore early Pleistocene. The Ratnapura fauna is thus a mixture, the result of frequent erosion and re-deposition, but that does not alter the fact that its discovery greatly extends the known geographical range of many Siwalik species.

The book is well printed and well indexed; the figures are good, the plates not quite so good. Mr. Deraniyagala is to be congratulated not only upon the book itself but also upon the years of single-handed work which lie behind it.

R. W. H.